NASA Technical Memorandum

MODIS DATA ACQUISITION AND PROCESSING SCENARIOS

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PREFACE

The purpose of this document is to provide MODIS Science Team Members with several working examples of data system operation as it may affect the MODIS instrument. The content of this document is derived from high-level statements of EosDIS and MODIS requirements and preliminary projections of data system structures that may meet these requirements. Besides describing basic data system structures, this scenario document includes outlines of person-to-data-system and person-to-person interactions that may affect or control system operation.

The data system structures and personal interactions described in this document reflect only the current thinking on system operation; structures will evolve as requirements are further refined and proposed system designs are more thoroughly examined for their ability to meet requirements. The Science Team Member should view this state of flux as an opportunity to obtain revisions in system design that will improve the ability of the data system to support his own research and meet the needs of the larger data user community. The data system structures and design philosophy embodied in this document should be reviewed by the Team Member to assure that all requirements have been met.

Several individuals besides the authors have contributed to the completion of this work. Early drafts were reviewed by John Barker, Wayne Esaias, Bruce Guenther, Chris Justice and Mike King at Goddard Space Flight Center and a number of helpful comments were received. We also gratefully acknowledge the excellent editorial and typing support provided by Brenda Vallette of Research and Data Systems.

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1. INTRODUCTION

The Moderate Resolution Imaging Spectrometer (MODIS) has been designated as a facility instrument on the first NASA polar-orbiting platform (NPOP-1) as a part of the Earth Observing System (EOS) beginning in the mid-1990's. MODIS (Salomonson et al., 1987) will be composed of two whisk-broom scanning instruments: MODIS-N, a 40-channel, nadir-viewing scanner (Salomonson et al., 1988); and MODIS-T, a 64-channel "tiltable" scanner (Maymon et al., 1988). As currently planned, the MODIS instruments will provide data to the user community with at least 15-year, continuous terrestrial coverage. The NPOP-1 will be in a 705-km altitude, Sun-synchronous orbit, with equator crossings at 1:30 AM/PM local time.

MODIS-T will scan $\pm 45°$ from nadir, will have a swath width of on the order of 1500 km, and will cover the entire globe at least once every two days. MODIS-N will scan $\pm 55°$ from nadir and will have a slightly larger swath width at about 2,000 km. The combined 104 channels cover the visible, near-infrared, and thermal infrared spectral regions. The channels have been selected to provide terrestrial, oceanographic, and atmospheric observations at spatial resolutions ranging from one kilometer to better than 250 meters at nadir. MODIS-T will take data at about a 1-km nadir footprint. MODIS-N will have three resolutions: 850, 430, and 215 meters.

A MODIS science team, composed of 24 investigators selected from institutions in the United States, France, England, China, and Australia, has been selected by NASA (see Appendix A). To accomplish the EOS objectives, these science team members will carry out scientific investigations with data from the MODIS research facility instrument leading to an improved understanding of various aspects of the Earth system, and will help NASA develop the MODIS instrument and analyze the resulting data.

1.1 THE MODIS GROUND DATA SYSTEM

The MODIS data system will be unique for the following reasons:

- An atmospheric, terrestrial, and oceanographic user community
- Global coverage and continuous operation
- Measured over 104 spectral channels
- Spatial resolution of better than 1 km
- Data products will be routinely archived as soon as 48 hours after observation
- Field experiments will be supported in real-time or near-real-time
- Over 100 products have already been identified
- On an average, one million observations per second will be taken
- Two million observations per second will be taken during the daytime
- Peak raw data rate of 20 Mbps
- 10^{12} bits of raw data taken every day

The MODIS data will be used by: the 24 members of the MODIS science team; other NPOP-1 facility and PI instrument teams; NPOP-2, EPOP, and JPOP instrument teams; interdisciplinary investigations; and the international Earth Science Community.

The MODIS data system drivers identified thus far in the effort include:

- 15-year mission lifetime
- <2% absolute calibration goal
- <1% stability goal
- 99.8% data completeness goal
- tight time constraints for production of standard data products
- thousands of MODIS data users
- 2,000 terabyte mission data volume
- massive data processing requirement (as large as 3 to 16 GIGAFLOPS)
- multi-instrument and multidisciplinary complexity

Based on the information compiled to date, we present here a set of scenarios identifying and describing the activities of the MODIS science team members within the MODIS ground data system. Based on the available science functional and performance requirements, the scenarios illustrate in both general and specific terms a preliminary concept of how the data system will support the activities of the team members. The interfaces between the science data processing facilities and the MODIS science team members will be emphasized.

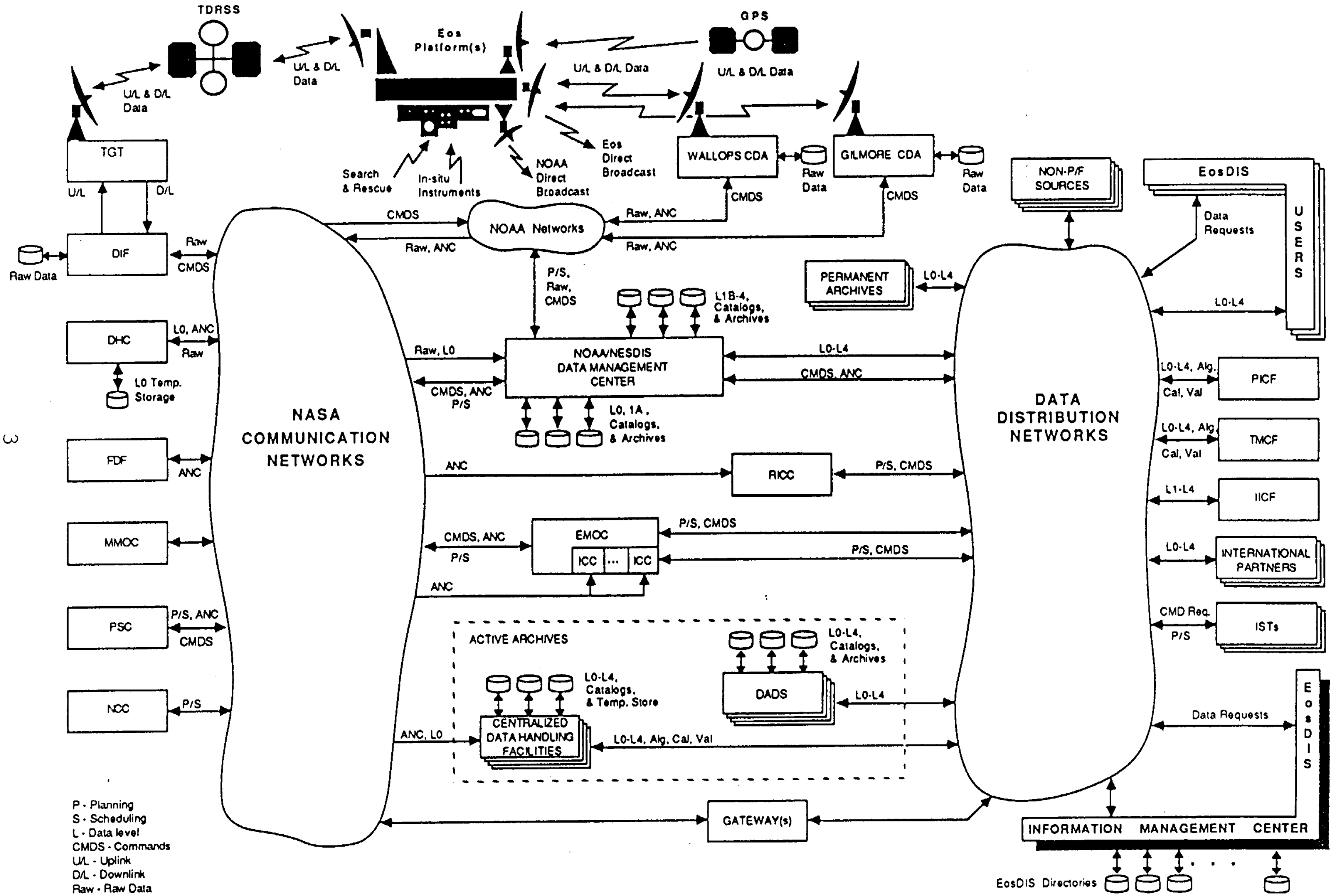
1.1.1 The Ground Data System in the EosDIS Environment

The EOS Data and Information System (EosDIS) will be responsible for the end-to-end data flows, as shown in Figure 1 (from EosDIS Baseline Report), involving the EOS Platform Data System, the MODIS Instrument Data System on board the platform, the Tracking and Data Relay Satellite System (TDRSS) and its White Sands ground terminals, the various EOS ground systems, and the users. Specific aspects of the EosDIS combine to shape the processing requirements for the MODIS data system; in particular, the release of certified data products in accessible archives within as little as 48 hours after observation. As a consequence of the design of MODIS instruments, a high data rate and an extremely large data archive volume are anticipated. The instruments are expected to have a data rate of from two to nearly 20 (night versus day) million bits per second (Mbps). Data will be generated continuously; the average data rate over an orbit is expected to be more than ten Mbps, with on the order of a terabit of raw data acquired on a daily basis.

1.1.2 Context and Data Flows for the Ground Data System

The EosDIS will provide data system support for all the Eos instruments. Specific components of the EosDIS will control and monitor the operation of the MODIS instrument on board the platform and perform the data acquisition, processing, and distribution functions to serve the user community. NASA's Goddard Space Flight Center (GSFC) is

Figure 1. Preliminary EosDIS Concept Diagram



P - Planning
S - Scheduling
L - Data level
CMDS - Commands
U/L - Uplink
D/L - Downlink
Raw - Raw Data
ANC - Ancillary Data
Alg - Algorithms
Cal - Calibration Data
Val - Validation Data

responsible for the design and development of specific elements of the data system within EosDIS. The system is being designed to fulfill the scientific functional and performance requirements identified by the members of the MODIS science team and other users, and will be operated within the context of the EosDIS (Figure 2). Because the science requirements will necessarily evolve now that the science team has been formed, as information is compiled and the instrument design developed, we anticipate some refinement to the design of the data system. Detailed information can be found in the reports by Han et al. (1988a, 1988b, 1988c) and Anderson et al. (1988).

The data system described in this document will not exist as a stand-alone entity; rather all data elements and data flows shown are within the EosDIS. However, since the complete EosDIS serves many instruments and contains elements not applicable to MODIS, this discussion addresses only those aspects of the EosDIS that are directly related to MODIS data tasks. For convenience, this subset of the EosDIS may occasionally be referred to as the "MODIS data system". In no way does such a reference imply that the "MODIS data system" will exist as an entity separate from EosDIS.

1.1.3 Functional Allocations within the Ground Data System

The allocation of the individual data system functions is illustrated in Figure 3. The ground data system can be seen to be comprised of five components: (1) the Instrument Support Terminal (IST), whose primary function is observation planning; (2) the Instrument Control Center (ICC), whose primary function is controlling and monitoring; (3) the Team Member Computing Facilities (TMCFs), whose primary function is algorithm development and data analysis; (4) the Central Data Handling Facility (CDHF), whose primary function is the generation of standard data products; and (5) the Data Archive and Distribution System (DADS), whose primary function is the archival and distribution of the data.

Through a consideration of the data flows in Figures 1, 2, and 3, the operations concept of the ground data system is revealed. The "upward" flow of information can be followed from a user, through the data system (the IST and ICC), to the MODIS instrument on board NPOP-1. Likewise, the "downward" flow of information can be tracked from the platform data system, through the TDRSS to the ground data system (including the CDHF and DADS), and then to the user (perhaps through the long-term archives).

1.2 THE TEAM MEMBER COMPUTING FACILITIES

The MODIS science team members will perform their research at distributed TMCFs. The individual facilities will be distributed nationally and internationally. Specific TMCFs may be designated to share in the generation of data products along with the CDHF.

Figure 4 is a context diagram of the TMCF. The TMCFs are distributed and are composed of project-provided computing facilities used to develop scientific and calibration algorithms, verify and validate data, and to generate some specialized data sets. The TMCFs are distributed networks at science team member locations and, perhaps temporarily, at the site of a field experiment (possibly through a field experiment terminal). It happens that several team members, including the team leader, are located at Goddard. The science team leader provides planning and coordination for the MODIS Science team members at the GSFC TMCF.

It is also planned that there will be an Instrument Characterization Team (ICT) resident at GSFC. The ICT will monitor MODIS instrument performance and develop and maintain instrument calibration. The Science Data Support Team (SDST) will assist in algorithm

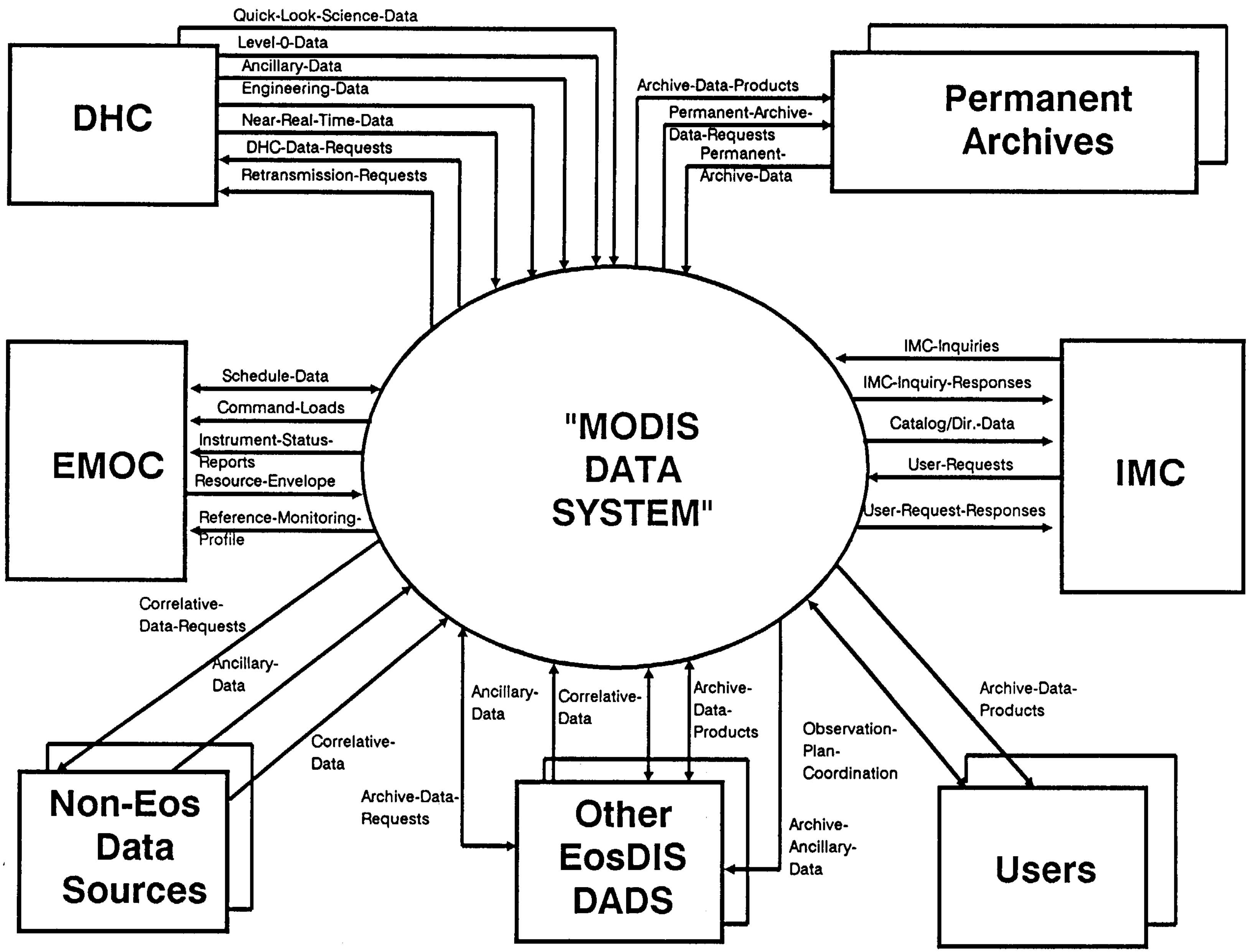


Figure 2. MODIS Data Context Diagram

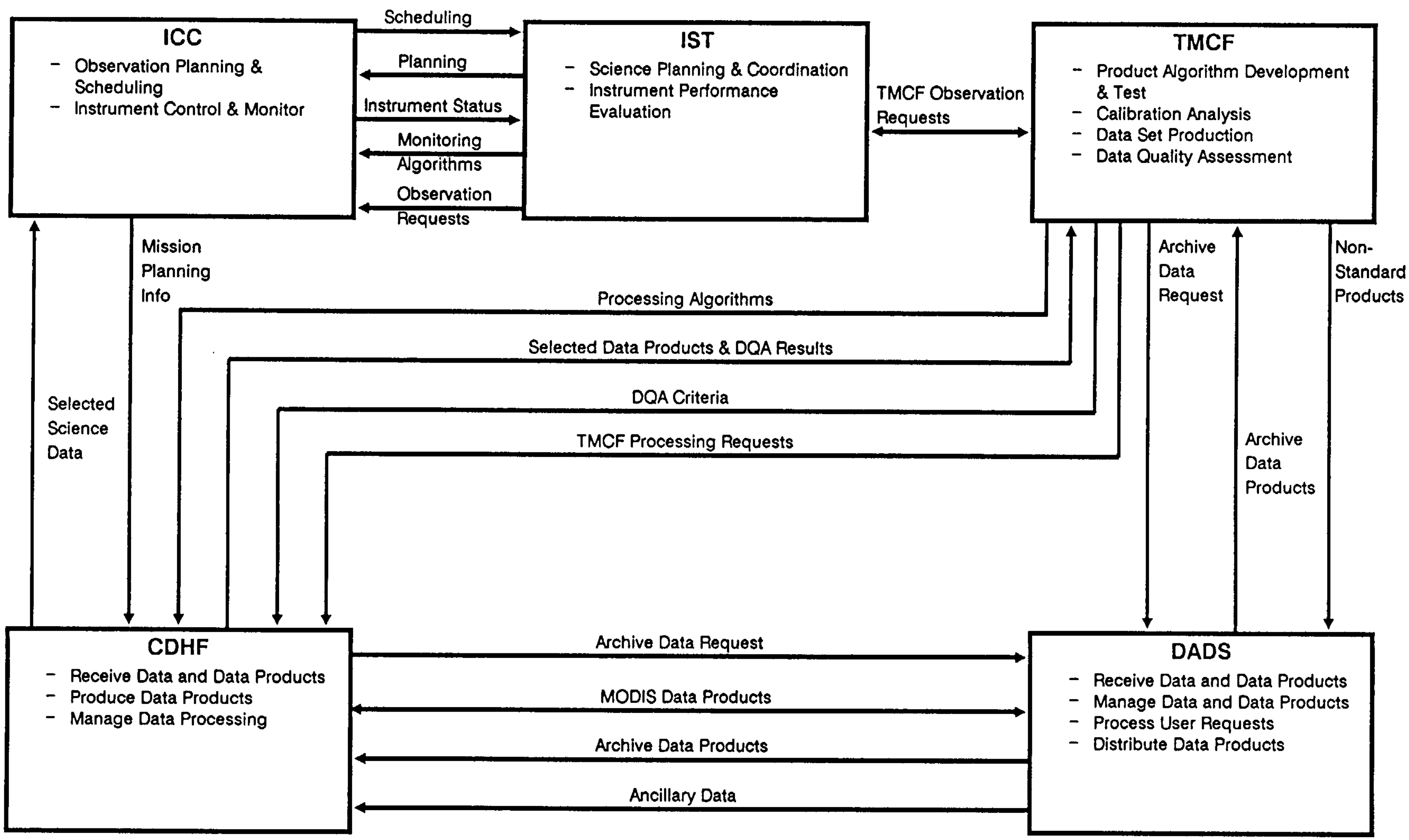


Figure 3. MODIS Data Functional Allocation Diagram

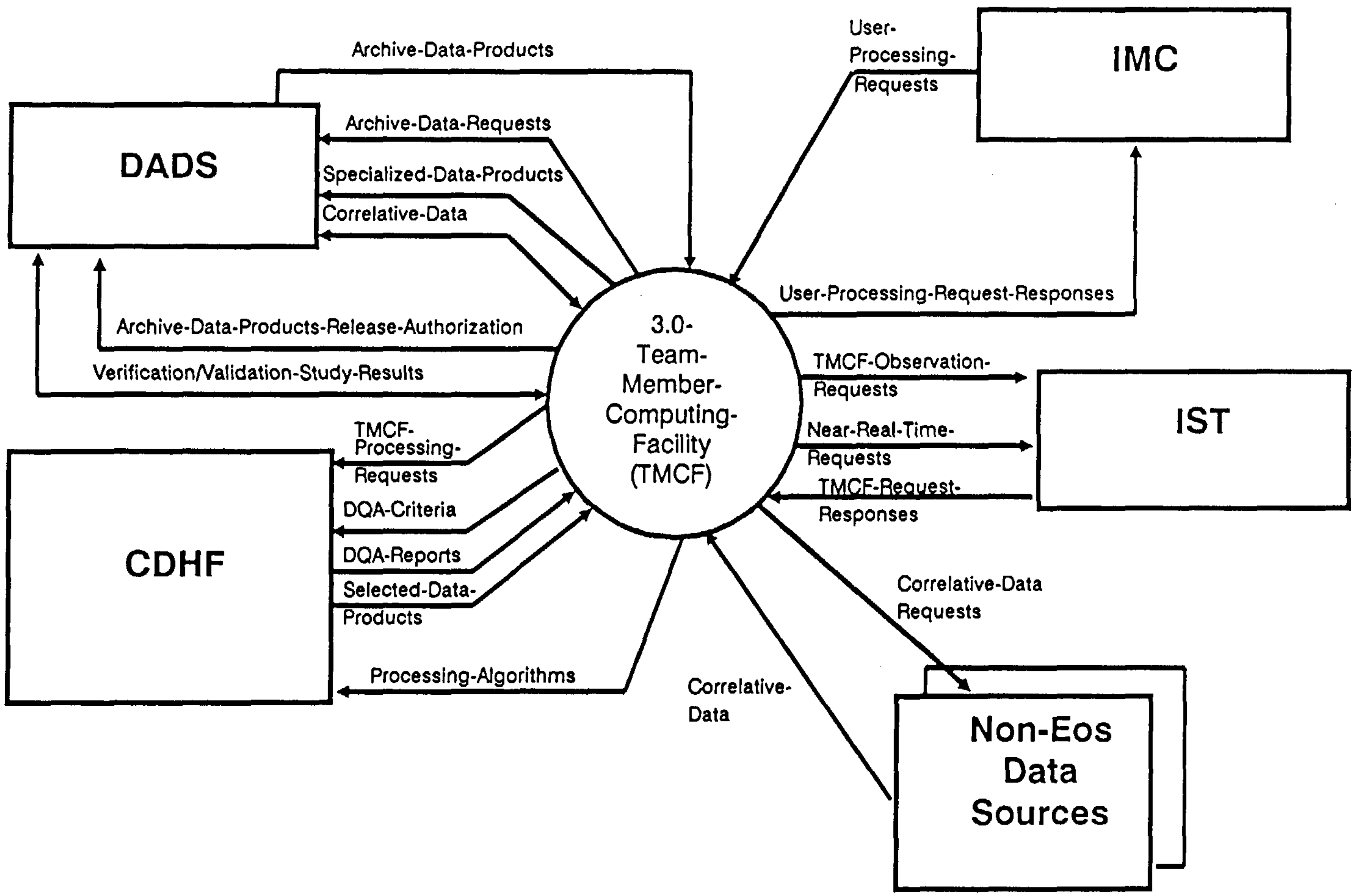


Figure 4. The TMCF Context Diagram

development. The SDST will help to make algorithms developed by the science team members more efficient and may develop software of utility to all team members. The SDST will assist in the development of Level-1 processing software.

In addition to communications which may be required between the TMCF's computers, each TMCF will require communications with: 1) the CDHF, 2) the DADS, 3) the Information Management Center (IMC), and 4) non-EOS data sources. Communications will consist of textual messages (as with the IST), interactive database inquiries (as with the IMC), and the exchange of data products, browse data products, and algorithms (as with the CDHF and the DADS).

2. MODIS SCIENCE TEAM MEMBER ACTIVITIES

The EosDIS will support a diverse set of MODIS science team member activities (Figure 5). These activities include: 1) planning and coordination; 2) data acquisition; 3) algorithm development and maintenance; 4) special data product production and archival; 5) performance of correlative and modeling studies; and 6) MODIS calibration development and development and maintenance, including all hardware and software required to support pre-launch instrument characterization. In the six sections below, we discuss the data systems' support of each one of the science team members' activities in turn.

2.1 TEAM MEMBER PLANNING AND COORDINATION

MODIS-N will collect data from 15 thermal-infrared channels at all times and from an additional 25 reflected-energy channels during daytime. MODIS-N will have a simple operations schedule due to its duty cycle and constant scan operation. MODIS-T will take data from 64 reflected-energy channels during the daytime only. MODIS-T, due to its design permitting tilt operations forward or backward with respect to the orbital velocity while scanning across a fixed Earth target, will necessitate a more complicated operations concept to meet the science requirements. The routine planning and scheduling of MODIS-N and MODIS-T will be dynamic in response to platform and communications changes, instrument anomalies, or activities unknown at this time.

Science planning and coordination involves implementing the Science Plan objectives from the Investigator Working Group (IWG) and data acquisition and processing requests which are generated by team members. This information is coordinated, prioritized, and integrated into an observation plan which is compatible with the high-level MODIS science policies. It is anticipated that, once routine operations are implemented, the planning and coordination activities of the team members will become minimal.

2.1.1 Planning and Coordination Organization

Planning takes place on many levels. NASA Headquarters provides long-term goals and objectives. This planning includes all the satellites and will not concern us further here. At the next level there is mission planning for a specific platform (NPOP-1) and is primarily done by the IWG. A Long-term Platform Science Plan (LTPSP) is the result.

The hierarchical levels of science planning and coordination encompass the IWG and the team members. The IWG and its international partners will assist the project and program scientists in defining the requirements of the scientific community.

One level down is planning for an individual instrument on a platform. The team leader and the science team members are responsible for developing a Science Management Plan (SMP) and Instrument Operations Plan (IOP). The SMP considers all aspects of MODIS

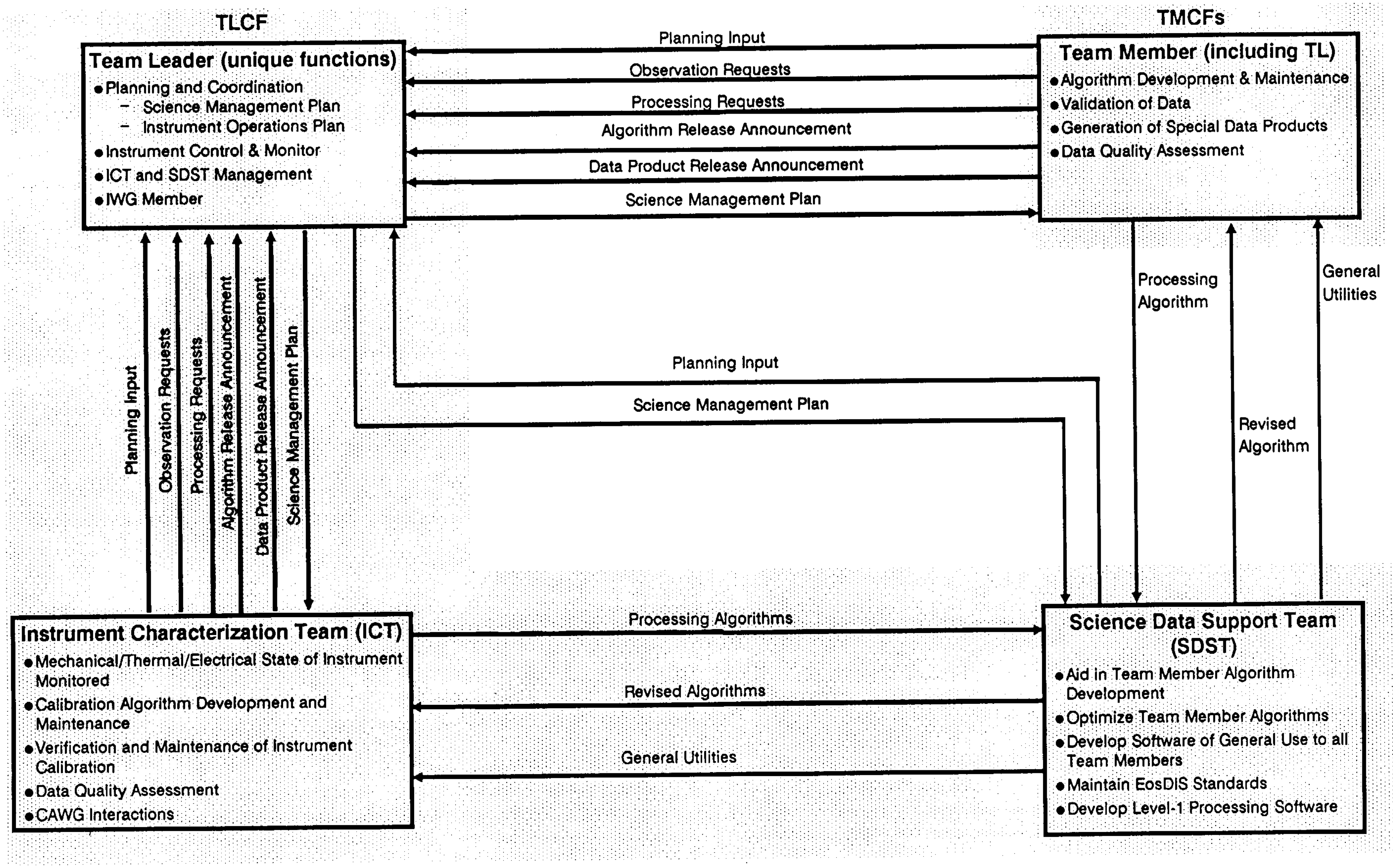


Figure 5. TMCF Functional Allocation Diagram

planning and is a combination of all the team member plans and proposals in one coordinated, conflict-free document. The SMP will probably cover about a year of planning and will be updated perhaps every three months. The IOP can be considered as part of the SMP or as a stand-alone plan which gives the spacecraft instrument plans for the next several months. The IOP will be periodically revised, perhaps every few weeks to months.

The lowest formal planning level is the task planning. For MODIS, an Instrument Operations Team (IOT) will develop a Weekly Instrument Operations Plan (WIOP) which will describe the instrument modes of operation for a one week period three weeks in advance. As part of this planning, instrument conflicts will be resolved and a final instrument command load will be generated and transmitted to the satellite.

All of these planning activities have one basic goal: the generation of a conflict-free instrument schedule which meets the highest level EOS science objectives. The plans at all levels are constantly being examined and revised. Many factors may lead to changes in the plans already developed, such as a Target of Opportunity (e.g., an explosive volcanic eruption) and contingency responses when the instrument malfunctions.

2.1.1.1 *Science Management Plan (SMP)*

The Science Management Plan for MODIS will define the science objectives and set the priorities for measurements and data reduction. The SMP will assign priorities to the science objectives so that MODIS manpower and hardware resources can be prudently utilized.

The plan will be updated periodically, allowing new investigations to begin and old ones to cease. For example, scientists may wish to use only one year of observations to derive bidirectional models. After this investigation ceases, new priorities will be assigned to the on-going data processing plans and the SMP will be modified accordingly.

The plan may also include cooperative investigations using other instruments and the sharing of data among many users. For example, cloud cover derived from MODIS data may be compared to cloud cover from other EOS instruments. Data may be exchanged in such studies. If the MODIS data are used in the calculation of parameters by other instruments, the plan will identify these multi-instrument measurement strategies and assure that sufficient resources are assigned.

A draft outline of the SMP for MODIS is shown below:

- I. Introduction
- II. Planning Considerations
    - A. Types of Internal Plans
        1. Data Processing Plan
        2. Calibration Implementation and Management Plan
        3. Instrument Operations Plan
        4. Target of Opportunity Plans
        5. Ground-Truth Experiment Plans

B. External Constraints on Planning

1. Interagency Planning Coordination
2. International Planning Coordination
3. Budgetary Constraints

C. Mechanisms and Procedures for Planning Input

III. Science Objectives and Associated Data Products

A. Atmospheric Aerosol Properties
B. Cloud Properties
C. Radiative Transfer Models
D. Land Surface Vegetative Properties
E. Carbon and Other Biological Cycles
F. Physical Properties of Land, Snow, and Ice
G. Ocean Biological Indices (Global and Regional)
H. Physical Properties of Oceans
I. Calibration Data

IV. Interdisciplinary Studies

A. Multi-Instrument Observation Coordination
B. Multi-Instrument Data Processing Coordination
C. Potential Data Products
D. Data Exchange and Format Issues
E. Performance Requirements
F. Ground-Truth Experiment Coordination

V. Resource Allocations

A. Manpower
B. Pre-launch Test Equipment
C. Instrument Control and Monitor Facilities
D. Computing Facilities
E. Data Access and Archiving Facilities

Some of the plans identified in the outline above have been identified in other documents and are discussed below. Other plans, such as a "Data Processing Plan," may or may not be written. They may simply be included in the SMP and not broken out as separate documents.

2.1.1.2 *Team Member Plans and Proposals*

Much of the material in the SMP may arise from the team members individual plans, which may be partly expressed in their proposals. Since these team member plans are written independently of each other and may have science objectives which are in conflict, some comments on conflict resolution is appropriate. Conflicts can arise in two different ways: different science objectives may require the instrument to be in different modes of observations, and an agreed upon MODIS mode of operation may impact other instruments on the platform giving rise to an instrument conflict. Conflicts over scientific issues are generally resolved by the team leader and team members. Instrument conflicts are generally solved by the IOT and EMOC, with some input from the team leaders or with the investigator working groups.

2.1.1.3 *Instrument Operations Plan (IOP)*

The Science Management Plan (SMP) will provide overall guidance for future MODIS instrument operations. Using the SMP as input as well as additional considerations such as routine requests for special observations, the team leader in consultation with the Instrument Operations Team will develop an Instrument Operations Plan, which will direct instrument operations over the next few months. As events warrant, the plan may be modified. The broad scope of the planning will need to fleshed out to give detailed weekly schedules, which are incorporated in the Weekly Instrument Operations Plan (WIOP).

2.1.1.4 *Weekly Instrument Operations Plan (WIOP) and Command Loads*

The WIOP provides a week's worth of information on the modes of operation of the MODIS instruments. The development of a WIOP starts one month prior to its implementation. The WIOP for MODIS is anticipated to be rather unchanging from week to week, because of the 100% duty cycle and probable even temporal spacing of the calibration modes. Special modes of operation other than these will be infrequent. A special mode might involve putting MODIS-T in a mode where one point on the Earth is scanned for the total period of time that it is in view. This mode is disruptive to the other objectives of the MODIS project and thus is expected to be used infrequently.

The WIOP developed by the ICC is expected to be accessible to the team leader through the IST, to the team members through an electronic bulletin board, and to all other users through the IMC. Finally the command loads are simply the machine readable and executable version of the final conflict-free WIOP. Prior to transmission to the satellite instrument, the command loads have undergone testing on the ground using a simulator. The IOT writes the command loads and tests them.

2.1.1.5 *Calibration Implementation and Management Plan*

The Calibration Implementation and Management Plan (CIMP) was identified in the Preliminary MODIS Calibration Data Products Plan (CDPP), and has been distributed. The CIMP covers all aspects of calibration and is not yet written. The CDPP may be incorporated into it, being an aspect of the calibration planning associated with calibration data products.

2.1.2 Science Team Roles and Responsibilities

The MODIS science team leader is a member of the IWG and it is through this interface that changes to the LTPSP are conveyed to the MODIS team members. The team leader will develop the MODIS SMP in accordance with the IWG LTPSP and input from other team members. The science management plan will be established for setting of priorities. This plan will outline prudent use of observation time and instrument resources, supervision of ongoing studies, dissemination of results, and monitoring of the instrument health. The science team leader will established the guidelines for the submittal of observation request to the ICC. After submission of request becomes routine, he may be involved only by exception or conflict. He will receive and catalog all team member and general user acquisition, data processing, and data product request.

Each team member will be responsible for the continued application of MODIS to complete the proposed research (e.g., one identified in the CIMP). Team member responsibilities to assure that MODIS instrument control is appropriate to support his research are in addition to the algorithm development and maintenance responsibilities delineated in Section 2.3. As the instrument becomes more predictable and new areas of science studies are discovered, the team member will generate data acquisition requests and send them to the team leader for approval. The team leader transmits these requests via the IST to the ICC for implementing the respective commands.

A data acquisition request, as opposed to an outright change to the science plan, may request unique instrument commanding, which is necessary to collect the data required for a particular science objective. This request may or may not become a routine instrument operation.

The ICT's functions are illustrated in Figure 5, and concentrate on the instrument calibration, including the development of calibration algorithms. Several team members with their supporting staffs may be members of the ICT. One or more team members or their designates will also be a member of the Calibration Advisory Working Group (CAWG). The ICT is a supporting group for the team members, and assures that the instrument calibrations are correctly maintained.

The SDST is another support group, concerned primarily with software development. They will aid team members in making their code efficient, so that whatever the architecture of the CDHF it will be optimally utilized. This could include vectorization of code or the development of software for efficient I/O. Since many team members may want to develop algorithms which accomplish nearly identical goals, such as plotting subroutines or other general utilities, the SDST will identify these common goals and either develop code to reach the general team member objectives or evaluate the competing codes so that the team members can decide which code is best. The SDST will also insure that EosDIS language standards and data product standards are met. The SDST will develop Level-1 processing software.

2.1.3 Science Plan Implementation

The team member will develop a request for controlling the MODIS instrument to acquire data and for the processing of the collected data. These request are discussed below.

2.1.3.1 *Data Acquisition Request; Instrument Control*

Science team members will generate a data acquisition request (DAR) for their planned science investigations in accordance with the MODIS IOP. The information included in this DAR is used to control the MODIS instrument. The DAR can be divided into the following areas of information with several examples given for each:

- Geophysical/Environmental Information:

  Observation Times
  Target Location
  Cloud Cover Parameters
  Surface Types

- Science Information:

  Science Objective
  Science Products
  Monitoring Requests

- Instrument Information:

  Tilt (MODIS-T) control
  Gain control
  Calibration sequence
  Duty Cycle Control

- Synergism:

  Other Instruments Required
  Other data required
  Timeliness

A DAR may also include information for the scheduling of observation data for support of field experiments, targets of opportunity, and calibrations. For example, field experiments may require calibrated radiances from 15 MODIS-N and/or -T channels at specific target locations, as well as the production of level-3 products, which must be processed in near-real-time (within three to eight hours of the observation). The field experiment information will then be incorporated into the baseline DARs for planning and coordination. Emergency situations may be handled with pre-generated commands.

2.1.3.2 *Data Processing Request*

As part of the planning and coordination, a team member may need to arrange for the routine or special processing of collected data, the generation of algorithms, and the distribution of processed data or results from the CDHF, TMCF, or DADS. This planning and coordination is performed independently from the aforementioned instrument control DARs. The planning and coordination of data processing will take place between the team member, team leader and the CDHF and requires a conflict resolution procedure for the prioritizing the processing needs of each team member. The team member needs to coordinate the processing of MODIS data collected per his instructions in the DAR. This coordination involves the collection and request of MODIS and other instrument data, platform ancillary data, engineering data, and other correlative (e.g., in-situ) data.

2.1.4 Data Acquisition Conflict Resolution

Once a DAR is submitted to the team leader, the team leader will merge the MODIS planning information with other request to identify conflicts with the science plan. The team leader will check the resource requirements of the instrument against the operations allocation and guidelines of the original planning input to the ICC. Conflicts may be caused by differences in requirements for individual scientific objectives, operating channels, by conflicts between science goals and system maintenance or communication schedules, by anomalous behavior of instruments or systems, or by near real-time requirements. Conflicts at this stage will be resolved iteratively in the science team domain by the application of the above guidelines and science priorities. If necessary, higher levels of resolution based on the long-term science plan and the IWG policies will be invoked. The prioritizing of processing request will also be coordinated by the team leader and will undergo a conflict resolution process.

A second level of DAR conflict resolution occurs in the ICC. The observation requests are checked against environmental models (orbit, attitude, Sun, and scene) to determine the feasibility of the request. For example, the required orbital geometry versus the predicted for support of a field experiment. The instrument resource requirements are modeled to the extent that the operations envelope is allocated by the EMOC. This envelope will provide guidelines for MODIS operation times and resources such as power.

It will be the science team leader's responsibility to convey the appropriate modeling parameters to the IOT. As the performance of the instrument becomes better known, the team member or leader will provide the IOT, via the IST, with changes to any instrument models. If IOT checks result in violation of the allocated resources, the IOT will inform the science team leader, via the IST, of the violation. The team leader and members will then resolve the conflict and a new or updated DAR will then be submitted. A candidate instrument schedule request is generated by the IOT, if no violations are found, and is sent to the EMOC for approval. All approved scheduling information is sent to the team leader via the IST.

2.1.5 Planning and Coordination Tools

Support tools will be provided by the IST, the TMCF, or through the IMC for access to a planning database to assist the team member in generating valid DAR and data processing request. The level of assistance is TBD and will depend on the user requirements, the system design, and the software developed. These tools may be portable so that the team member can access them from any location. The tools should provide for off-line generation of the DAR and data processing request before being sent to the team leader for coordination and approval.

2.1.6 Planning and Coordination Interfaces

The team member or Leader, can generate and submit a DAR and data processing request from any TMCF location that has the appropriate tools. To optimize this activity, a standard format will be agreed upon for delivery of requests. A DAR may be electronically transmitted to the team leader in two ways, either directly through an on-line interface or via the IMC. The IMC will provide the appropriate communication service, (communication lines and menu driven displays) for transmission of the request to the team leader. The team member may be able to submit a request by phone or mail services if necessary. In all cases, a coordinated observation request made up of individual DARs will be sent through the IST to the ICC under the control of the team leader. Data processing request will be handled separately using a TBD interface with the CDHF, TMCF, and DADS.

2.1.7 Planning and Scheduling Timeline

The science plan and policies determined by the ~~IIWG and~~ IWG will be completed months in advance of a DAR generation. The DAR will undergo the coordination, authorization, and approval process at the discretion of the team leader before the request is sent to the ICC. To ensure that a DAR can be honored, it is necessary to enter a DAR into the IOT's planning and scheduling activities four weeks ahead of the planned observation time. The ICC planning and scheduling process, which includes development and maintenance of the WIOP, continues for approximately three weeks. During this time, the schedule is iterated with the EMOC and team leader/members to resolve conflicts. Approximately one week ahead of the planned observation time, the DAR is considered scheduled and command loads are generated. The command loads are sent to the EMOC a few days before their upload to meet EMOC and PSC requirements.

The team members may update their request at any point of this timeline up to two orbits before the execution of the command load by the instrument. The update should follow the same conflict resolution hierarchy as before. If the request is due to a target of opportunity or emergency need, the most expeditious method available may be pursued to accommodate the request.

A request for priority or special processing of data and the need for ancillary data from EOS and non-EOS data sources must be known at a TBD time before the MODIS or other instrument data are collected.

2.2 DATA ACQUISITION AND PROCESSING

The data collected by the MODIS instruments will be transmitted to the Data Interface Facility (DIF) on the ground via TDRSS. The data received by the DIF will be sent to appropriate Data Handling Centers (DHCs) At the DHC, the data will be processed to Level-0. Bit errors that occur during transmission may be corrected at the DHC. The DHC will also collect and transmit ancillary data, such as platform ephemeris and platform attitude data, to the CDHF, where standard data products are produced. Level-0 and ancillary data will be available within 24 hours of observation.

In addition to these routine instrument operations and processing of science data, there will be two special modes of operation: instrument calibration-related observations and field experiment support. Instrument operations to monitor calibration sources can be included as part of an observation, or may be dependent upon internal or external calibration sources.

Science team members may request special observations for their planned science investigations. Observation requests may include information for the scheduling of observation data for support of field experiments. Field experiments may require calibrated radiance data as well as higher-level products, at specific target locations in near real-time (within three to eight hours of the observation).

Level-0 data will be further processed at the CDHF. Ancillary data will be merged with Level-0 data to produce Level-1A data. Earth locations are computed and radiometric calibrations are performed on the Level-1A data to produce Level-1B data. The radiometric calibration algorithm will be provided to the CDHF by the Science Team. The team members will also provide standard data product generation algorithms to the CDHF. Using these algorithms, Level-2 data will be produced from Level-1B data and other necessary data. These Level-2 data, as well as Level-1B data, will be used to produce Level-3 data, which are maps on fixed Earth grids. Level-1 data will be available within 48 hours of observation, Level-2 and Level-3 data will be available within 96 hours of observation. Browse data and metadata will be available with the same timeliness as the standard products.

2.2.1 Requesting MODIS Datasets

The standard and special data products archived at the DADS will be available to users upon request. The users' access to the DADS is centralized and handled by the IMC. The IMC will store the most recent information on data production status, as well as catalogs of the MODIS data products. Browse data may be available at the IMC. The users will specify their needs and place orders, and the IMC will route the requests to the appropriate DADS. The DADS will copy and send the requested data to the user via the requested method, which may be either electronic or on some physical media. In most cases, the data will be sent within 24 hours of receipt of the request.

After approximately two years, the data will be transferred to long-term archive centers. In this case, the IMC will provide the user with information describing where the data may be found.

As presented below, data acquisition encompasses the Science team member's requests for MODIS datasets, non-MODIS EOS datasets, and non-EOS datasets. Figure 4 illustrates the data resources and flows available to the TMCF.

MODIS-N and MODIS-T Levels 1-4 datasets will be requested by team members through the IMC or directly from the DADS by team members. These team member requests will be entered either interactively or executed as standing orders. The requested datasets will be retrieved either from DADS storage or from the permanent archive facilities, and sent electronically or on off-line media to the requesting team member. Team members can also request browse, catalog, and/or metadata from the IMC or DADS.

2.2.2 Requesting non-MODIS EOS Datasets

Non-MODIS EOS datasets will be requested through the IMC or directly from the DADS. Facility instruments providing this data include the Atmospheric Infrared Sounded (AIRS), Geoscience Laser Ranging System (GLRS), High Resolution Imaging Spectrometer (HIRIS), Laser Atmospheric Wind Sounder (LAWS), and Synthetic Aperture Radar (SAR). Some of the P/I instruments providing this data include the Tropospheric Emission Spectrometer (TES), Lightning Imaging Sensor (LIS), High Resolution Research Limb Sounder (HIRRLS), Ionospheric Plasma and Electrodynamics Instrument (IPEI), Stratospheric Wind Infrared Limb Sounder (SWIRLS), GPS Geoscience Instrument (GGI) for Eos and Space Station, X-Ray Imaging Experiment (and Optional Particle Detectors), the Solar Stellar Irradiance Comparison Experiment (SOLSTICE), Spectroscopy of the Atmosphere Using Far-IR Emission (SAFIRE), Earth Observing Scanning Polarimeter (EOSP), An Active Cavity Radiometer Irradiance Monitor Experiment, and, Microwave Limb Sounder (MLS).

These requests will be entered either interactively or as standing orders. There will be two types of availability for these datasets. The first type will refer to datasets already in existence. The second will refer to datasets produced only when requested, for example, HIRIS datasets. In the first instance the DADS will request the datasets be sent from another EOS DADS or a permanent storage facility. In the second instance the DADS will forward a request for the datasets. When they are available (either at the time of the request or when generated) they will be sent by the other EOS DADS to the DADS electronically or on off-line media. Upon arrival at the DADS these datasets will be forwarded on the specified media to the requesting science user.

2.2.3 Requesting non-EOS Datasets

The team member will be provided with information to access desired non-EOS data. Data products resulting from these inputs will be sent to the DADS for cataloging and eventual access by other users. The non-EOS data will not be archived at the DADS if they are archived somewhere else. The Non-EOS satellites and/or instruments expected to be sources of this data include GOES (I-M), NOAA Polar Orbiters (such as AMSU and AMRIR), SeaWiFS, LANDSAT, SPOT 1-4, and the Japanese Earth Resources Satellite (JERS-1), ADEOS, MOS-1, GMS, IRS-1, ERS-1, METEOSAT, China's Earth Resource Satellite, Canada's Radarsat, Brazil's Remote Sensing Satellite, GREM, TOPEX/Poseidon, N-ROSS, UARS, GEOSAT, GPS, LAGEOS-1, and DMSP. The method by which non-EOS data are to be obtained is TBD.

2.3 DEVELOP AND MAINTAIN ALGORITHMS

The science team members are responsible for developing science algorithms to process the MODIS data. This section describes the overall process by which this developmental work is accomplished within the environment from the point of view of the team member.

2.3.1 Team Members and Algorithm Development

A MODIS science team member will be responsible for developing science algorithms using either his own computing facilities or project provided computing facilities. He is also responsible for documenting his algorithm. The SDST will be available to help the team member to both examine the code and modify it as required to make it efficient and to meet EosDIS standards. All of the science algorithms will be tested and run on the CDHF (or duplicate facility) to see if they 1) compile, 2) execute and generate results meeting certification criteria, and 3) are efficient.

Assuming an efficient working version of the algorithm is developed and has been certified as correct, the team member will write an Algorithm Release Announcement containing information on the algorithm and its data products. The announcement will be reviewed by the team leader before general release.

Algorithm development is an on-going process and will follow the general outline above throughout the MODIS experiment. A scenario which gives a chronological summary of this procedure is given in Section 3.6.

2.3.2 Science Data Support Team (SDST)

The SDST consists of computer scientists and other supporting personnel whose functions are: 1) to assist the Team Leader in reviewing all software and associated documentation, 2) developing Level-1 processing software, 3) assisting team members to make their computer code more efficient without any sacrifice in accuracy, 4) developing computer code of general utility to all team members, and 5) helping the team members to assure that the code developed meets EosDIS language standards and to assure that MODIS data products conform to EosDIS standards. In all software matters, the SDST will assist the Team Leader in assuring the readiness of the algorithms for the CDHF.

The science team members using the TMCF are responsible for the development of calibration and science algorithms. The SDST will provide assistance and guidance as directed by the Team Leader. Activities may include the coordination of input/output algorithms and plotting and imaging algorithms which are of use to all science team members; these will be developed either by the SDST or team, or will be purchased from commercial sources.

EosDIS is expected to establish computer language standards and data product standards. These standards will probably adhere to some international standards. Their objective or requirement will be to have transportable and maintainable code and to generate data products that can be compared to other EOS products or to non-EOS data products, without a considerable overhead of effort. The SDST will be familiar with these standards and examine the MODIS algorithms to ensure that the EOS objectives are being maintained. They will aid the algorithm developers in reaching the EOS standards.

Rather than have several team members develop code which accomplishes the same task, the SDST will help the Team Leader in coordinating the development of this code. The SDST is meant to be a resource for the use of all team members.

2.4 PRODUCE AND ARCHIVE DATA PRODUCTS

Appendix A lists candidate data products proposed by the MODIS science team members.

2.4.1 Standard Products

All collected MODIS data will be processed to scientifically usable data levels. Data processed to higher-level data at a central data processing facility, the CDHF, are called standard data products. The descriptions of the processing levels at which standard data products will be produced are given below:

Level-0: Time-ordered instrument data, redundancies removed, bit-error corrected, and quality-assessment annotated.

Level-1A: Instrument data with ancillary and engineering data needed to complete processing appended. Earth locations are computed and reversible radiometric calibrations have been applied. The highest level of data from which it is possible to recover the Level-0 data.

Level-1B: Level-1B data are irreversibly processed from Level-1A, and will only be produced if the MODIS Level-1 processing generates data products from which Level-0 data cannot be recovered. Under these circumstances, both Level-1A and -1B products will be produced and archived.

Level-2: Geophysical parameters derived from Level-1B data, and at the same resolution as Level-1B data.

Level-3: Radiances or other geophysical parameters that have been geometrically rectified and resampled onto space-time grids.

Level-4: Model or analysis results of lower-level products from the MODIS instrument and products from other instruments or sources.

There will be other types of standard data produced from the above data products. These data will contain summaries of products, coarse resolution data, or other information, and include:

Browse Data: Browse data products accompany all archived data products and are provided to assist data users in selecting data that is suitable for their purposes. They are not meant to be used as input to processing algorithms that produce higher-level parameters from lower-level products. In addition, the date or dates of observations, instrument type designators, product type designation, spectral band, and instrument tilt angle for each image may be displayed on the browse images.

Metadata: All MODIS data delivered to the archives may be handled in blocks, or "granules;" each granule will have appended a descriptive header describing the data within the block. In the archive, this header data will be used in a data base management system (DBMS) to facilitate a user's access to the full-resolution and browse resolution MODIS data for display and ordering purposes.

In addition to standard data products, there will be other types of data products archived and available to users. These special data products are considered to be part of a specific research investigation and are produced for a limited region or time period. New or experimental products may eventually be accepted by the research community as standard products and will then be processed routinely. The special data products should meet the same requirements as the standard data products.

2.4.2 Special Products

It is likely that there will be a significant amount of processing that is done by MODIS team members. The current working definition is that a Special Data Product is anything not routinely produced in the standard product generation on the CDHF. By this definition, almost anything done by a team member, and delivered to DADS, will result in a Special Data Product.

2.4.3 Other Products (Possibly Specialized or Standard)

This section will contain a discussion of four specific types of special data products:

a. Non-standard products
b. Preliminary products
c. Level-4 science products
d. Interactive products

The presentation will consider only scientific or geophysical analysis. This report contains additional discussion of this topic in the sections on algorithm development and calibration.

2.4.3.1 *Non-Standard Products*

MODIS team members will be responsible for the production of, at least some, science products that will not be generated during standard processing at the CDHF. This could involve the production of science products which are required only infrequently or in special circumstances.

For the support of field experiments, team members may produce special science products that are roughly equivalent to standard products. As an example, the chlorophyll content of the tropical ocean could be determined by combining MODIS data with data from a geosynchronous satellite and a NOAA platform. It might not be possible to obtain all of this data and do the processing within the several hours required to support the field experiment. The field experiment would be supported by a team member who would make a less accurate estimate using only Level-1B MODIS data. This product would be passed to a team member in the field, or perhaps generated in the field. This product may or may not be sent to the DADS since a more accurate product will be produced in four days by the standard processing.

2.4.3.2 *Preliminary Product*

During algorithm development, there will be a point at which the product being produced is correct and of scientific value. There could still be a substantial amount of work to be done before the algorithm could be implemented on the CDHF. This could be either software development or validation studies. As an example, an algorithm may be producing good science but be far from conforming to software standards.

How this situation is to be handled will depend on the demand for the data. It may be possible to wait till the algorithm is fully certified and then produce the product on the

CDHF by reprocessing data. If there is immediate demand for the product, the results could be distributed as an uncertified product. (We are not aware of a mechanism for the distribution of uncertified data products.)

2.4.3.3 *Level-4 Science Products*

Level-4 Processing is not well defined at this time. In particular, it is possible that all Level-4 Processing will be nonstandard. This may place a severe load on the team member computing facilities. At least some of the Level-4 processing will be done by team members. There will be Level-4 products produced only rarely or perhaps just once. As an example, following a volcanic eruption such as occurred at Mt. St. Helens a Level-4 product could be produced which shows the spatial and temporal evolution of the dust cloud. It will be necessary to archive and distribute Level-4 products. At this time, it is unclear how this will be done. It clearly will be necessary to produce products that conform to all of the EOS standards.

2.4.3.4 *Interactive Processing*

Certain types of processing are done interactively, i.e., a trained operator examines a preliminary or partial data product and guides the processing based on his expertise. It will be possible to automate some of this type of processing, e.g., check for cloud cover before determining surface properties. The MODIS science team members are cautioned that only a limited (and still to be determined) amount of interactive processing involving the CDHF will be possible, and this may be restricted to non-standard (special) data products.

The CDHF may not permit interactive processing; there may not be real-time interaction with a team member. Any processing that must be done interactively will be done by a team member. This is likely to involve the use of a graphics work-station, and may require significant computer resources. In addition, this type of processing will probably be done to support field experiments.

Interactive processing will produce data products that will be difficult to certify. When interactive processing is done, the result depends on the decisions made during the processing. Two different team members will make different decisions which will generate different results. The differences can be significant. It is not difficult to document the decisions made by the operator and thus generate a detailed history of the data product. It is very difficult, if not impossible, to assess the quality of the final data product when a scientist's subjective judgments play a part in the processing.

2.5 PERFORM VALIDATION STUDIES

The MODIS science team will perform correlative and modeling studies to validate and determine the accuracy of MODIS science products. This effort will involve the analysis of correlative data to determine the correctness of the MODIS data products and statistical modeling of both the MODIS instrument and the data products to determine the accuracy of the results.

2.5.1 Correlative Studies

Correlative data will be obtained to verify/validate the performance of the MODIS instrument. Correlative data are defined as any geophysical parameter that is not a MODIS data product. This will include data products from other instruments on the MODIS platform, data from instruments on other EOS platforms, and data from non-EOS sources. EOS data will be requested by a team member from the DADS. It will be possible to obtain this data simply by issuing a data request. The data to be obtained from non-EOS sources will include "ground truth" observations. Examples are upper air meteorological radiosonde data, rainfall data collected at a ground-truth network, and cloud cover as observed from a vessel in the Pacific Ocean.

The team member will decide what non-EOS data are needed, determine if the data are available, and arrange to obtain the data. The details of how this will be done is TBD. It is clear that non-EOS data may not be available without significant delay. In-situ data from an ocean cruise might not be available until the ship returned to port, i.e., a delay of several weeks.

While the data from non-EOS sources may not be of the same quality as EOS data, it will still be necessary to obtain ground truth observations to verify the correctness of the MODIS results. For example, it will be necessary to measure surface temperature in-situ to insure that accurate values are obtained.

2.5.2 Modeling Studies

Modeling studies will be required to determine the accuracy of the MODIS data products. There may be some MODIS data products which can be more accurately measured with other EOS instruments, e.g., AIRS may more accurately determine atmospheric temperature profiles. For these products, the errors can be modeled by comparing the MODIS results with the more sensitive measurements of the other instrument.

The accuracy of some products may be monitored by taking repeated observations of a quantity which is constant or slowly varying over a period of time. An example might be the surface temperature of the Arctic Ocean. A time series of observations of the same geophysical parameter could be examined and modeled to determine the accuracy of the MODIS data.

It is likely that the accuracy of some of the MODIS data products will be determined from pure modeling studies, i.e., Monte Carlo or computer system simulations. For any geophysical parameter, the known errors on the input data and the recovery algorithm can be used in simulations to estimate the accuracy of the parameter. This method will require knowledge of the statistical errors on the calibrated data, which will be determined by the calibration procedures.

It is possible that the result of both the correlative and modeling studies will be an instrument performance model. The performance model would contain information on the statistical errors on the MODIS data products as a function of the relevant parameters. This model would be an important tool in long-term monitoring of the MODIS instrument.

2.6 MAINTENANCE OF THE MODIS CALIBRATION

Several science team members are interested in the calibration of the MODIS instruments in the sense that a major portion of their efforts will be directed towards maintaining an accurate instrument calibration. All these team members and their supporting staff are expected to be members of the ICT. The ICT is expected to be involved in all aspects of calibration. The account of the ICT given here is thus not a definition of the team, but rather a treatment of its role in regard to calibration data products and data processing.

Team members who are not part of the ICT can become involved in calibration as described in Sections 2.6.1 and 3.4. The role of the ICT is included as background (Section 2.6.2) and is taken from an earlier document called the Preliminary MODIS Calibration Data Products Plan. It is written from the point of view of the team members who are part of the ICT and describes how they interact with other elements of the data system.

2.6.1 Team Members who are not ICT Members

Science team members may have questions about the instrument calibration. The ICT's responsibilities include providing answers to these questions. The ICT will keep a log of these questions and the answers provided. The ICT will provide a user's guide to document the MODIS calibration procedures. The ICT is a resource for any activity associated with calibration procedures and algorithms.

2.6.2 Team Members who are also ICT Members

For the calibration to be as accurate as required by the science team, it is anticipated that early in the Phase-C stage of the MODIS instrument development a ICT will be formed. This team will be composed of science team members and supporting staff which includes physicists, instrument engineers, and computer scientists. Its primary responsibilities prior to launch will be assuring that the ground calibrations are properly performed and provide continuity in the calibrations between the pre-launch and in-flight periods. The ICT will also develop the calibration algorithms in the pre-launch period. After launch, its primary responsibilities will be providing the calibration coefficients and algorithms to the CDHF. This latter duty requires a host of supporting responsibilities which include monitoring, analysis, and assistance. The operation and responsibilities of the ICT are reviewed below. Information on external interactions of the ICT is followed by a review of its supporting internal functions.

2.6.2.1 *ICT/CDHF Interactions*

A primary responsibility for the ICT is developing calibration algorithms and supplying them to the CDHF. These algorithms will remain relatively stable and only occasionally require updates. If an update is required, the CDHF will be supplied with the new algorithm. Approval of this procedure will be made by the team leader and the science team.

The primary in-flight responsibility of the ICT is providing the CDHF the necessary calibration coefficients so that Level-1 data can be generated on schedule. The ICT will probably accomplish this task by acquiring special subsets of Level 1A data from the CDHF, in some cases to analyze views of selected earth targets, or data involving the use of the solar diffuser plate to monitor the instrument calibration. This data will be analyzed to see if the calibration of any of the detectors has changed. If they have changed, the CDHF will be provided with new calibration coefficients so they can proceed to process Level 1 data. On occasion the ICT may send the CDHF a processing request, such as a request to perform calculations which the ICT does not have the resources to perform.

2.6.2.2 *ICT/IST/ICC Interactions*

A primary responsibility of the ICT is providing the ICC via the IST a request for a special operation mode for MODIS when it is needed for calibration. The team leader at the IST will determine the priority of these calibration requests, along with the science requests, prior to relaying them to the ICC.

2.6.2.3 *ICT/DADS Interactions*

The ICT will provide special data products to the DADS which document the history of the calibration of the instrument. Sample data products are 1) calibration scenes, 2) night views (visible channels), 3) history of lamp outputs, 4) history of blackbody outputs, 5) history of spectral calibrator, and 6) history of the lamp monitoring detectors. The DADS will also archive the calibration coefficients.

2.6.2.4 *ICT/Instrument Contractor Interactions*

Prior to launch, the calibration performed by the instrument contractor will be overseen by the ICT so that the science team goals are met. The ICT will ensure that the instrument's calibration is traceable to NIST standards. The team members and the ICT will perform these tasks.

2.6.2.5 *Internal Functions of the ICT*

A primary responsibility of the ICT is the on-going monitoring of the calibration of the MODIS instruments. The ICT will meet the time schedule and quality assurance requirements for the generation of Level 1B data products. The ICT will build a mathematical model of the instrument in order to interpret changes in the instrument performance and to develop calibration algorithms. Documentation of these models through technical reports or scientific papers are data products associated with this activity.

The instrument calibration coefficients may be a function of time. The ICT will monitor the trends in the coefficients and based upon these analyses provide updated coefficients. The ICT will conduct on-going studies of the calibration algorithms. The ICT may request that MODIS operate in special modes from time to time to check the calibration. Such modes may be, for example, looking at selected Earth targets, looking at the moon, using a stereo view mode, and so forth.

The ICT will have resources to determine the causes of changes in the instrument calibration, so that changes in the calibration can be corrected based upon solid physical principles. The mathematical model for the instrument is one basis for these studies. As a further check on the instrument calibration, comparisons of the calibrated MODIS instruments with themselves or with other calibrated satellite and in-situ measurements is a necessary activity of the ICT. The ICT will have the capability to participate in instrument intercomparisons in an on-going program to verify the MODIS calibration.

The ICT will be in contact with the contractor during the Phase C/D studies. Continuity of the Calibration Group and Instrument Group from Phase C/D through launch will be maintained by the ICT. The ICT will collaborate with science team members and evaluate the relative merits of different calibration algorithms.

3. SPECIFIC MODIS SCIENCE TEAM MEMBER SCENARIOS

Here, we consider how the MIDACS will support the MODIS science team member's activities by illustrating five specific scenarios: 1) routine interactions, 2) targets of opportunity, 3) field experiments, 4) MODIS calibrations, and 5) algorithm development and implementation. Though the scenarios are specific, the procedures identified are generally applicable to a diverse set of related activities. Issues related to requirements on the data, including fulfilling the team member's requirements, are provided in Appendix B.

3.1 SPECIFIC SCENARIO ILLUSTRATING ROUTINE INTERACTIONS

The following scenario presents the routine interactions of the team member and team leader with other segments of the data system. This scenario for the routine production of land, ocean, and atmosphere data is presented here as an example of a general type of planning and coordination, and data processing and storage. Three areas of scientific specialty are combined into the routine interactions of the data system. Although they are shown separately to clarify the interactions within the data system, processing is considered to take place concurrently.

3.1.1 Routine Planning and Coordination

The planning and coordination of three scientific scenarios is discussed below and, as shown in Figures 6, 7, and 8, is performed within the box marked MODIS science team on each figure. It is assumed that the instrument models used by the ICC have already been developed by SDST and tested and approved by the team members and are in-place at the ICC. It is anticipated that once the routine operations are implemented, the planning and coordination activities of the team members will be minimal, if performed at all.

3.1.1.1 *Routine Team Member Participation*

The team members have previously decided on a routine observation plan to pursue. Since this is a routine scenario, the planning and coordination activities have been completed following the procedures discussed in Section 2 and the team member is not required to submit another plan unless he wishes to update or change the routine instrument operations.

3.1.1.2 *Routine MODIS Data System Participation*

Using the IST, the team leader has previously submitted an observation request to the instrument operations team (IOT) located at the ICC for weekly conflict resolution and command load generation. The routine observation plan, the supplied instrument models, and EosDIS resource envelopes are used to ensure allocated resources are not exceeded. If a conflict exists which prohibits the use of MODIS, such as tilting during a portion of the requested observation time, a notification of the conflict and related information is then sent back to the team leader via the IST. The team leader resolves the conflict with the respective team member. This is shown in the figures by the data flow marked conflict resolution. Upon approval of the schedule by the EMOC, the IOT generates the command loads for this request and they are implemented at the appropriate time.

The routine planning and coordination of MODIS is simplified by the nature of the instrument and the number and type of commandable instructions. Since the duty cycle of MODIS-N and -T are projected to be full-time (100%; 50% for the reflected energy channels), a set of commands such as those for pointing (tilt), gain, and day/night mode switching can be routinely uploaded. For the routine observations using MODIS-N, there are no special observation sequences needed for this scenario other than the duty cycle and on/off modes of operation based upon the IWG plan and guidelines. For the Ocean scenario, an observation request sent to the ICC for the MODIS-T instrument contains an optimized tilt mode operation to avoid Sun glint. For the Land scenario, a MODIS-T stare mode is requested.

3.1.2 Routine Data Acquisition

It is assumed in these scenarios that the team member has developed and tested the processing algorithms on the TMCF resources; the algorithms are again tested in final form on the CDHF prior to implementation in routine processing. It is also assumed that the observation request has been honored and that MODIS data is available to the CDHF from the DHC for processing.

3.1.2.1 *Routine Data Processing*

Routine processing of the MODIS data takes place at the CDHF. This processing requires three basic interactions to be performed; ingest of MODIS science data and MODIS ancillary data from the DHC, ingest of additional data, if required, from other data sources such as other EOS DADS, and the processing of MODIS data to provide the team member with his product. This scenario assumes that the Level 1-3 processing is done in sequence.

The routine scenario for atmosphere is presented in Figure 6. It shows the generation of cloud parameters which require the coprocessing of data from two other instruments. These instruments, AIRS and AMSU, provide temperature, humidity, ozone, and cloud parameter data at a coarser resolution than MODIS. In this scenario, the team member has generated a standing request for these data to be sent to the CDHF from archive on a routine basis. The request is made either by direct communication with the DADS or through the IMC. These data may be radiances for products which have already been processed to derive atmospheric temperature and water vapor profiles or surface temperatures. Level 1-3 cloud product data sets are routinely produced by the CDHF using the MODIS-N Earth-located and radiometrically calibrated data and the AIRS/AMSU data. As part of the routine processing, cloud products are archived in the DADS after generation by the CDHF. The team members requests that this data be routinely sent to him along with ERBI[1] OLR, GOMR[1] ozone, and selected in-situ (radiosonde, aircraft, ship, etc.) data. Again, this may be a standing request filled automatically by the DADS, at a requested time interval.

The routine ocean scenario, Figure 7, shows the routine processing to generate ocean productivity and photosynthetic efficiency. Both MODIS-N and -T data are required to generate this product. This scenario does not require the use of other instrument data to generate the product required by the team member. After the ocean products have been generated, they are sent to the DADS for dissemination to the team member at his request as previously stated. The team member analyzes and compares this data using correlative, in-situ, and similar products from other studies such as SeaWIFS and CZCS. Results of team member activities and any new products are sent to the DADS for archive and distribution.

Figure 8 presents the routine scenario for land snow products. MODIS-N and -T data are required along with MODIS ancillary data. MODIS Level-2 snow products are generated at the CDHF using only MODIS data. Similar to the above scenarios, the team member has previously requested that related snow products from other studies such as AMSR, AMRIR, and occasional SPOT and Landsat data be sent to him for analysis of his

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[1]Preliminary; MODIS team member proposals submitted prior to EOS instrument selection.

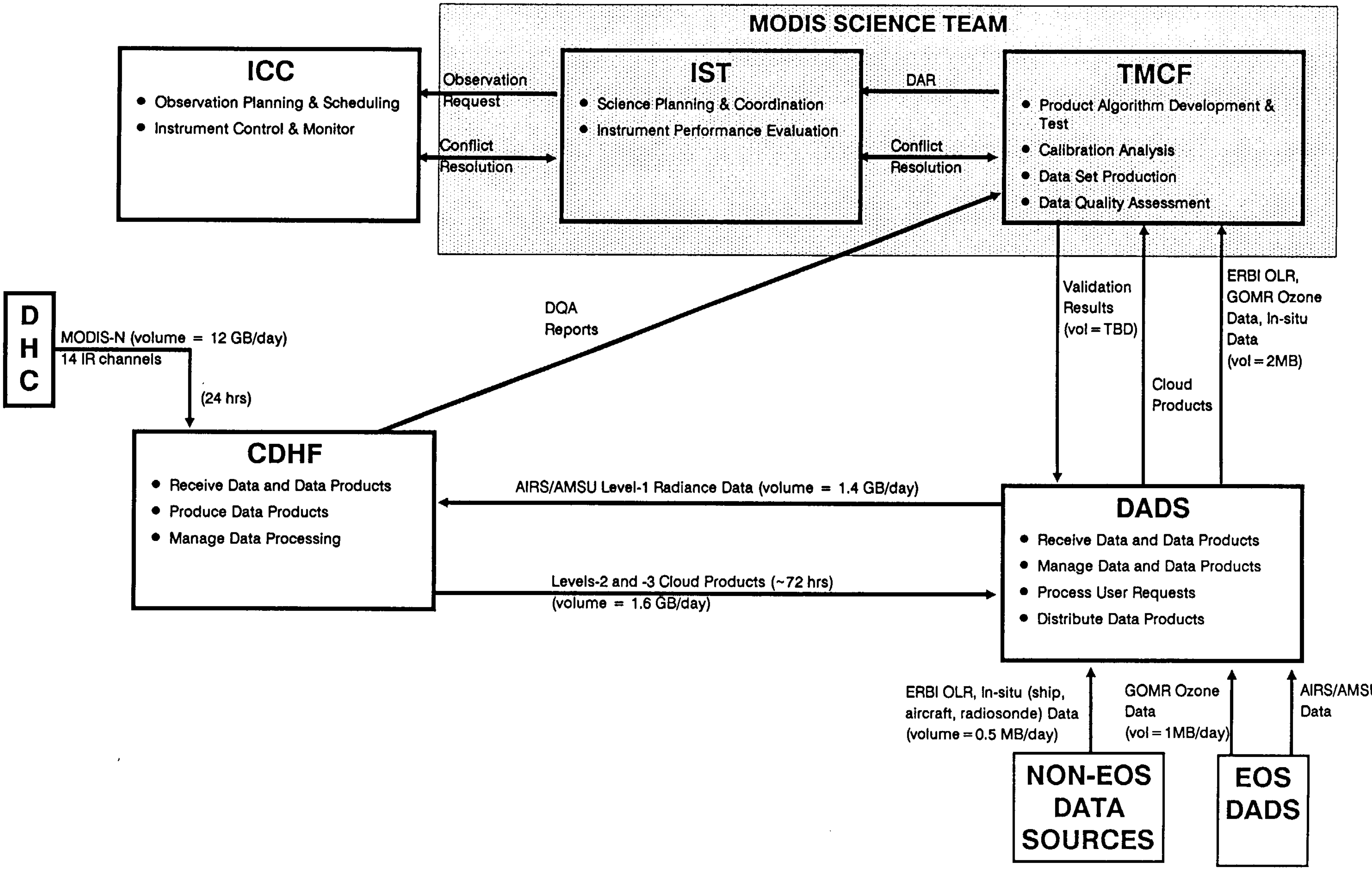


Figure 6. Routine Interaction Scenario for Atmosphere

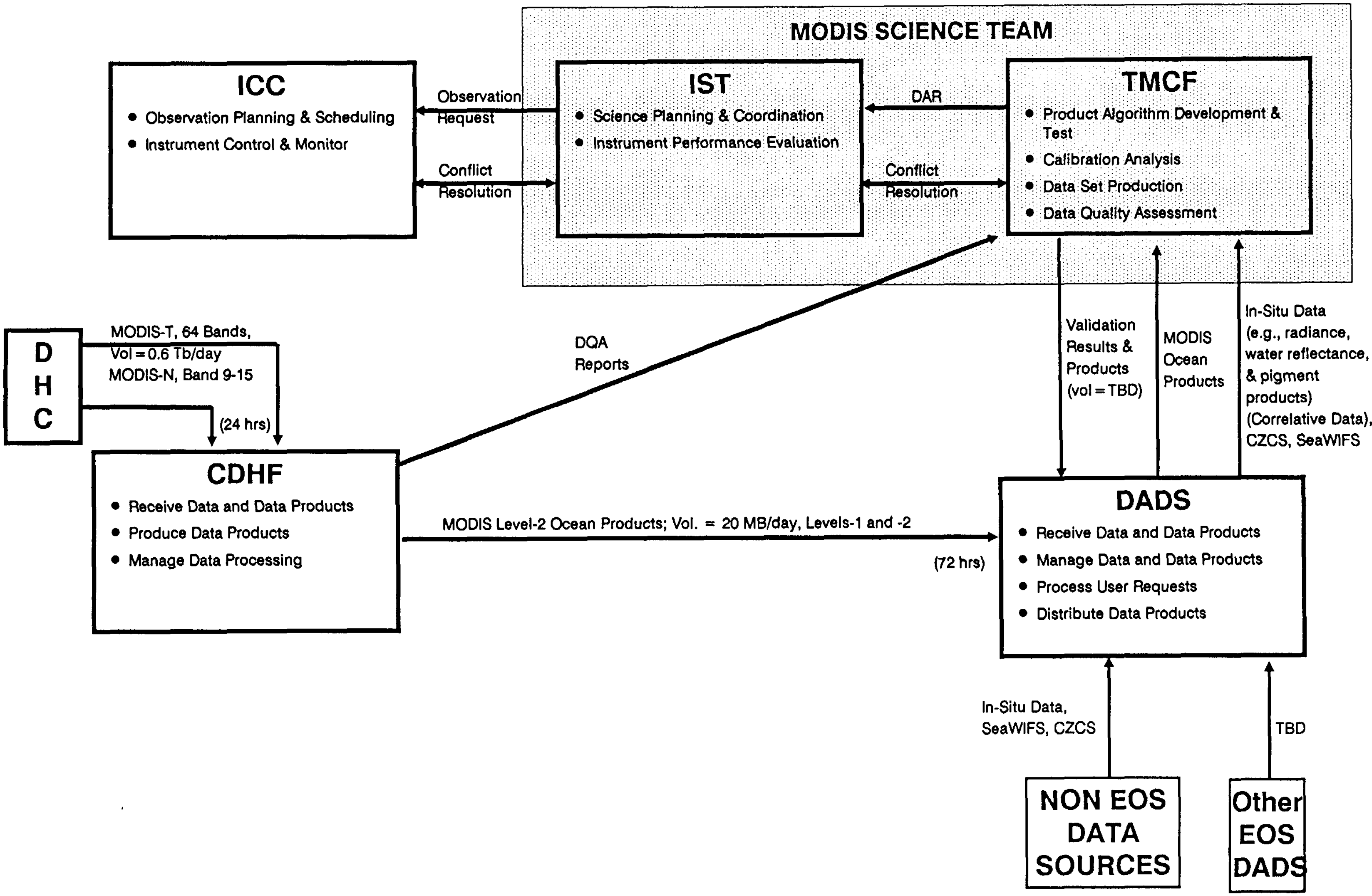


Figure 7. Routine Interaction Scenario for Ocean

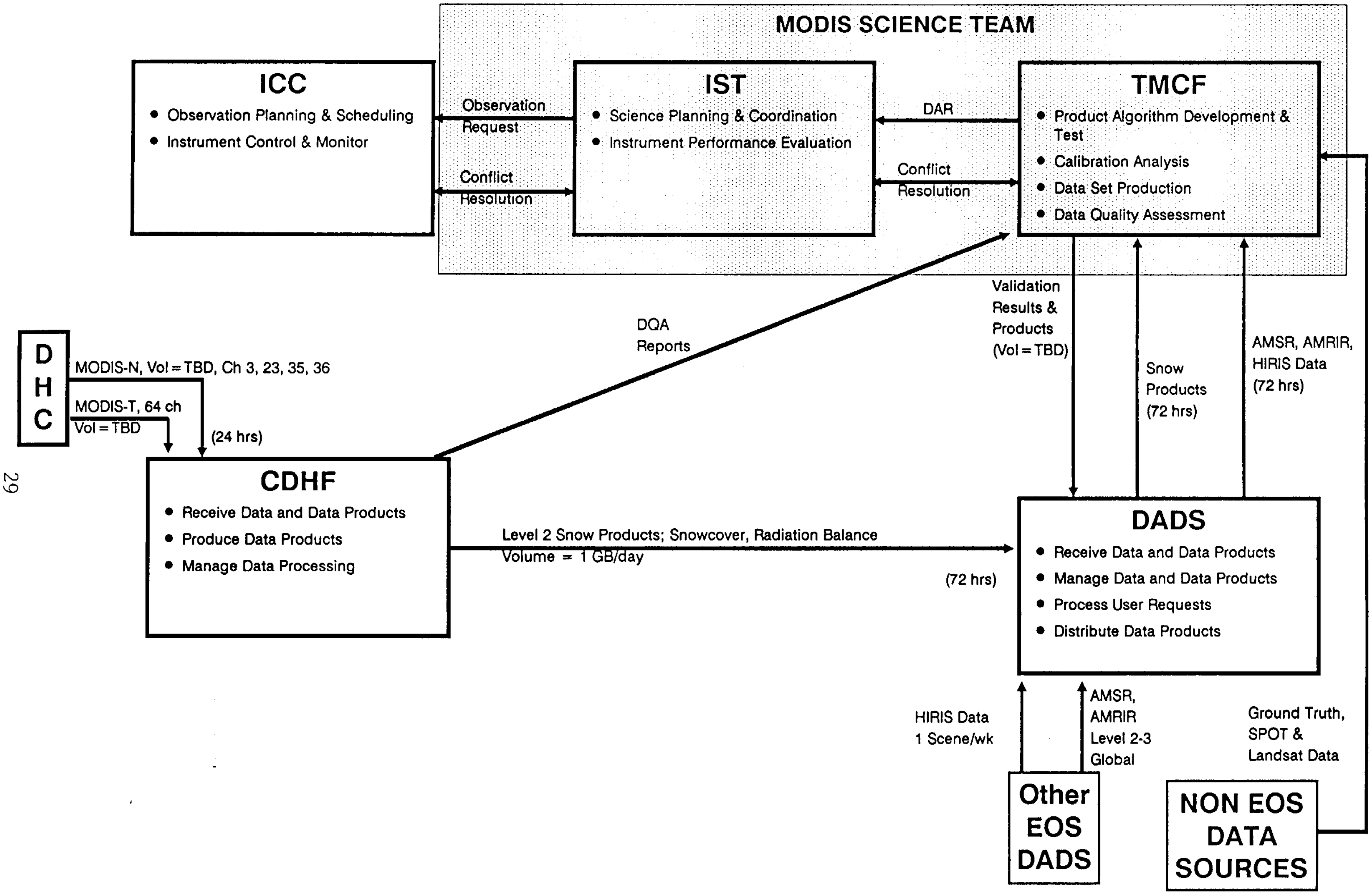


Figure 8. Routine Interaction Scenario for Snow

processed data. Analysis results and new products generated by the team member are then sent to the DADS for archive and distribution.

During and after the processing of data by the CDHF, the team member receives data quality assessment (DQA) reports related to the processing of the requested data. The DQA contains statistical and quality assessments of the ingested and processed data and of the processing system.

3.1.2.2 *Routine Data Storage*

All products generated by the CDHF are routinely sent to the DADS for active archive. The team member accesses his data by requesting it either directly from the DADS or through the IMC using a TBD (menu-driven) system. These data are sent routinely to the team member either electronically or via a physical medium. The team member can request data from other studies through the IMC or DADS which enable him to validate and verify his results. This may be a routine operation that is performed at the team member's discretion. All data sets and validation results are then sent to the DADS for subsequent release to the public.

3.1.3 Summaries

The following table presents some of the expected team member activities. Some of these activities may only occur as an exception once the observations and processing become routine. The team member may chose to receive his data either electronically or on a physical medium.

3.1.3.1 *Activities*

Team Member Action	Reason/link
Submit DAR (also conflict resolution)	Propose observation plan, implemented for coordination; Electronic link from TMCF to team leader
Submit Observation Request	Generation of commands and EOS resource conflict resolution; Electronic Link to ICC
Submit Data Processing Request	Select and prioritize data processing; Electronic link from TMCF or IST to CDHF
Submit Data Request	To Receive MODIS and other archived data; Electronic link to DADS or IMC; Receive data electronically or on physical medium

3.1.3.2 *Timeline*

The following table presents a routine timeline of activities.

Activities	Timeline	FROM/TO
1. Plan/Coordinate	Weeks-Months before routine operations	
Observation		TMCF/ICC
Synergism		TMCF/ICC
Other Data		TMCF/CDHF-DADS

2.	Receive MODIS data	Within 24 hours from the DHC	DHC/CDHF
	Receive ancillary data	At time interval specified by team member	Data Sources/ DADS DADS/CDHF
3.	Process Data Level-2 & Up	Within 8 hours after receiving data	CDHF/CDHF
		Within 72-96 hours after receiving data	
4.	Receive MODIS data	After processing data, 72-96 hours or at team members discretion	CDHF-DADS/TMCF

3.2 SPECIFIC SCENARIO ILLUSTRATING TARGETS OF OPPORTUNITY

Dynamic phenomena, such as explosive volcanic eruptions (EVE), insect infestations, and human produced or related events, will be detected by MODIS. These events represent targets of opportunity for scientists and require a quick response by the scientist and ICC to study these phenomena. The scientist, assumed in this scenario to be a science team member, will notify the science team leader of an ongoing event. As illustrated in Figure 9, specific information necessary to operate the MODIS instruments to study this event will result in the generation of command or observation request by the science team leader which is sent to the ICC via the Instrument Support Terminal. These requests will impact the current schedule at that time.

3.2.1 Planning

Since the majority of EVE events are not predictable, the following scenario discusses data system operations for an unpredicted event. The request does not follow the current instrument schedule. The science team member delivers a request to the science team leader at the IST/TLCF for intensive observation of the explosive volcanic eruption. Since the team member request has a significant impact upon the present plan and instrument schedule, the team member must present his case for alterations of the plan to the team leader. Since an EVE is of wide scientific interest, the team member's request is expected to be approved.

The team leader may be presented with multiple requests for MODIS operations. The time pressures for immediate data acquisition may place the team leader in a position where he will be unable to consult all team members before arriving at a decision as to which mode of operation MODIS should be placed in. In this case, the team leader will decide which course of action to take. The Science Management Plan may provide a pre-determined and agreed upon plan of action for EVE's and other contingencies. Whatever the course of action, an approved observation request is then transmitted via the Instrument Support Terminal to the ICC. As an example, this observation request may contain the following information.

EVE: Eruption of Mt. St. Helens
EVE start time and duration: 1998, July plus six weeks
EVE location: State of Washington, USA

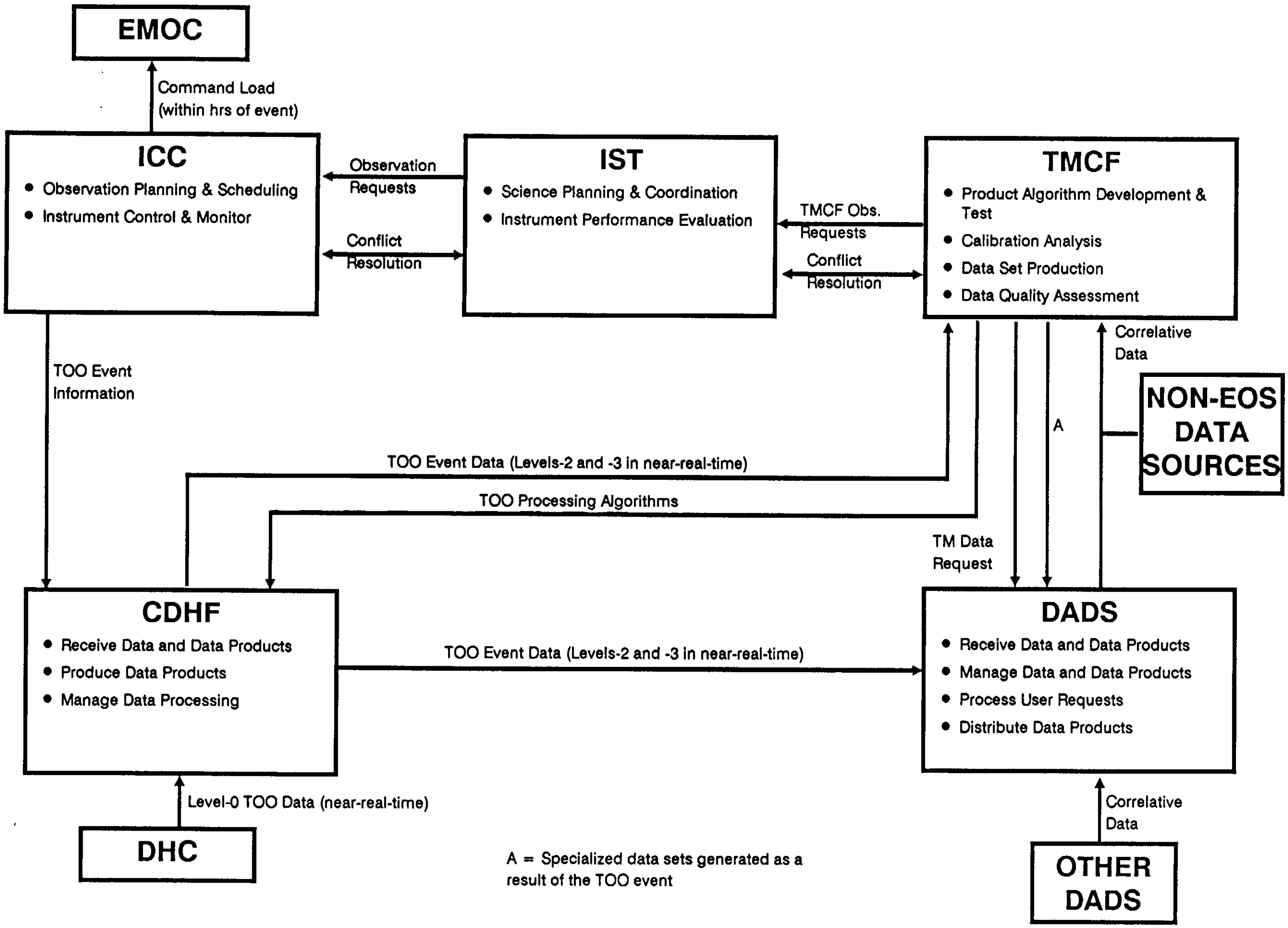


Figure 9. Target of Opportunity Scenario

Timeliness requirement: Daily, each observation opportunity for the next 6 weeks
Near Real-time requirements: First day (day to day decisions thereafter)
Instrument Unique Operations: MODIS-T in stare mode in each pass over the site

All the team members, as well as the requesting team member, will be kept informed of the changes in the observation plans by the science team leader. The MODIS science team leader is the point of contact for all follow-up information and for additional status requests. The science team leader may have a designated assistant to perform most of these mission related duties.

In addition to observation requests from MODIS, the team members may also wish to acquire data from other platform instruments for synergistic studies. If these Eos data products are routinely generated, he can contact the IMC to acquire the necessary data. For non-Eos data, the team member may need to acquire it on his own from other data centers.

3.2.2 Scheduling and Commanding

The IOT at the ICC will respond in an appropriate manner to a target of opportunity request. To minimize turnaround time, the ICC may use pregenerated commands developed for such an event or generate the commands from a simulation of the request. The latter may be a shortened process due to the nature of the request. The command load is then verified and sent to the EMOC for resource conflict review. The commands are then uploaded to the instrument according to standard procedures during the next available TDRSS contact. If the event is to be observed in near real-time, command loads will be generated to assure that the instrument properly tags the instrument packets for near-real-time processing. Once the EVE event is over or the duration time span of the observation request to monitor the EVE is exceeded, commands will be issued by the IOT to resume the current weekly schedule that was interrupted.

3.2.3 Monitoring

The ICC will notify the CDHF of the request in order for the CDHF to provide the appropriate processing functions and will notify the science team leader of the status of the request. The IOT will monitor the engineering and science data to ensure that the instrument is responding to the command load. If an anomaly is discovered in the operations, corrective action will be taken by the IOT upon approval by the science team leader.

3.2.4 Data Processing And Archiving

Processing the data from EVE will be done in near-real-time. The CDHF will contain, or be provided with, code to provide the near real-time processing for the event as requested. Presumably an event of this nature will be planned for and algorithms will have already been developed to study the EVE. These algorithms will be submitted to the CDHF by team members. An EVE event with MODIS-T in a stare mode during a portion of many orbits may require special processing at the CDHF. A special data product may result, such as the production of a film of the eruption plume using many flybys of the event at the TMCF. The DADS stores and transmits the data to the originator of the request.

3.3 SPECIFIC SCENARIO ILLUSTRATING FIELD EXPERIMENTS

This is a specific, hypothetical example of a field experiment that might be supported by MODIS data. As shown in Figure 10, this scenario is intended to illustrate how the MODIS science team members will accomplish the objectives of a coordinated observing campaign.

The field experiment is a three-month campaign to observe the interaction of the Gulf Stream with the Atlantic Ocean. It is assumed that this investigation involves three MODIS team members and two other research institutes. This experiment will combine EOS data with in-situ readings taken aboard ship and by buoys dropped from aircraft. These data will be used to examine two key areas: the dynamic evolution of the vortices created at the margin of the Gulf Stream and, the variation of ocean parameters normal to the boundary of the Gulf Stream and the Atlantic Ocean.

3.3.1 Observation Plan

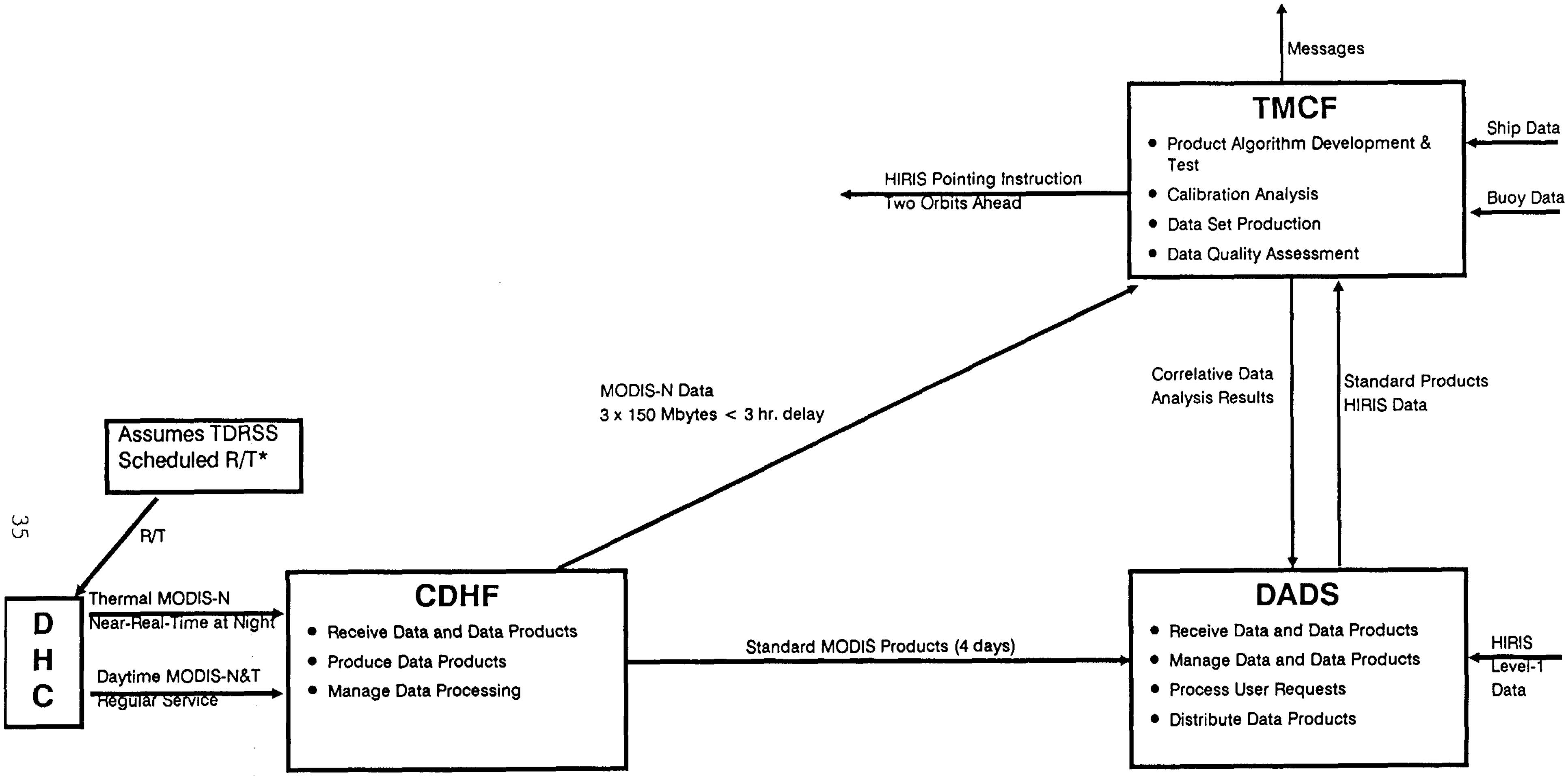
The general scheme is to use MODIS-N nighttime data to observe the edges of the Gulf Stream with 1-km resolution. The MODIS data products will be used to point the HIRIS instrument, direct the cruising on surface vessels, and guide the placement of surface buoys. MODIS-N and -T data will also be acquired from the daytime passes.

The surface vessel(s) will take data along 10-km tracks normal to the boundary of the Gulf Stream and the Atlantic Ocean. Each vessel will need to know the location and orientation of this boundary. It is assumed that each ship carries a Global Positioning System (GPS) receiver so that the position is known to better than 100 m. The ships will collect in-situ data and water samples for comprehensive analysis.

The vortices will be studied by imaging with MODIS and HIRIS and by dropping buoys into the center of the vortex from a Navy P-3 aircraft. The buoys will be equipped with a temperature sensor and a GPS receiver to track the dynamical evolution of the vortex. After the disturbance dissipates, the buoys will be recovered by a Navy ship.

There will be severe time constraints in this scenario. The MODIS data will be analyzed and used to control the HIRIS pointing for the next afternoon. The HIRIS targets must be selected 3.5 hours before the observation is to be made in order to allow time for scheduling and conflict resolution. The MODIS-N nighttime data will be collected and sent through TDRSS and the DHC to the CDHF within approximately 3.5 hours of observation. The team member at his TMCF node requires a little time to examine the map and decide on the appropriate HIRIS target(s) (e.g., 1.5 hours). This would require that the CDHF process the data and transmit the result to the TMCF within approximately 3.5 hours.

After selecting the appropriate targets, the MODIS team member will generate a HIRIS observation request. It is assumed that in the previous arraigned HIRIS schedule there is provision for two observations to support this experiment on each of three successive orbits. The MODIS team members need only select the geographic location of the targets and scheduling software will generate all the necessary commands. It is assumed that the HIRIS and the daytime MODIS data can be processed in a normal fashion and that for HIRIS processing instructions will be included in the observation request.



*In general, however, TDRSS may not be scheduled and data will be tape recorder playback

Figure 10. Field Experiment Scenario

3.3.2 Experiment Schedule

It is assumed that work on this experiment will begin approximately one year before the first observation (see Table 1). It is further assumed that formal agreement between the various participants has been reached at this time. It is assumed that three months of planning, scheduling, and negotiations between the various agencies results in a preliminary plan and the firm commitment of all the required non-EOS resources.

Six months prior to the beginning of the experiment a preliminary EOS observation plan will be generated. This plan will be sent to the MODIS and HIRIS team leaders and the IWG. Approval by the IWG will be required since there will be a significant EOS resource required for this experiment. After conflict resolution, the resources required for this experiment will be allocated in the long-term plan. It is assumed that the required TDRSS resources will be requested at this time.

A significant amount of software development will be required to support this experiment. The software development is scheduled for the period of 3 to 9 months before the experiment.

It is determined that the boundary of the Gulf Stream is most easily observed using the thermal channels of MODIS-N at night. It is likely that sea-surface temperatures will be routinely derived using the thermal channels of MODIS-N combined with ancillary data from other EOS instruments. However, in this scenario it is assumed that only MODIS-N data will be used. It is determined that this will require that a special algorithm be written and implemented. In particular, it is determined that, due to the severe time requirements, it will be necessary to pass the Level-0 data directly from the CDHF to the TMCF.

To map the full extent of the interaction region will require 15 minutes of data from three successive orbits. Approximately 150 Mbytes of data will be received for each orbit. Only the portion of the data covering the region of interest will be processed. The processing will be done by a team member at the TMCF node. The data will be calibrated using previously determined calibration coefficients, and surface temperature calculated. This will be non-standard processing, and algorithms must be developed to accomplish this.

An algorithm will be developed that combines the three orbits and produces a single, geometrically rectified map of sea-surface temperature. The processing will be done on, and the resulting map displayed on, a graphics workstation. The maps will be visually examined to look for new vortices. Another algorithm will automatically determine the position and orientation of the Gulf Stream boundary. (Note: It is assumed that clouds will be visible in the surface temperature map. Determining how to deal with cloud cover will be a significant activity during the software development phase.) This will be a specialized MODIS data product generated within the TMCF.

Approximately one month before the beginning of the experiment the team member generates detailed observation plans for MODIS and HIRIS. By exercising the scheduling software available at the TMCF, the team member determines that it is possible to download all of the nighttime MODIS-N data in real time. Requesting this service is allowed by the priority level of this experiment and the data are scheduled for real-time transmission to the ground terminal and for forwarding to the DHC and CDHF with no significant delay.

Table 1
Time Schedule for Gulf Stream Experiment

Pre-experiment Activities	
T - 1 year	Project begins.
T - 9 mon.	Preliminary experiment plan developed. Software development begins.
T - 6 mon.	Observation plan submitted to EOS. TDRSS resources requested.
T - 3 mon.	Software development finished.
T - 1 mon.	Detailed observation requests submitted. TDRSS scheduled.
T - 2 day	Final pre-observation update to schedule.
For Each Day of the Experiment	
T + 4 hours	All nighttime MODIS data received at TMCF.
T + 7 hours	Data processing done, map display available.
T + 8 hours	Target lists for HIRIS prepared, schedule updated.
T + 10 hours	Messages sent to Navy and surface ships.
T + 12 hours	Daytime HIRIS and MODIS observations begin.
T + 15 hours	Buoys deployed.
After the Last Day of the Experiment	
T + 4 days	All of the MODIS and HIRIS data available in DADS.
T + 1 mon.	All ship and buoy data received by team members.
T + 4 years	Analysis finished. All results available in data archive.

It is determined that the normal daytime and nighttime operation of MODIS is required for this experiment. Therefore, the team member issues a request which locks MODIS in the normal observations mode for the duration of the experiment over the domain (unless a higher priority request comes along). A HIRIS data acquisition request is initiated which gives the observing times and acquisition mode (e.g., channel selection). The HIRIS request will be updated with pointing information about two orbits prior to the actual observation.

The preliminary request is approved and updated one week and two days prior to the beginning of the experiment. Finally the experiment begins. The first observation is taken at 11:30 PM local time. The Level-0 data from the first orbit is available at the TMCF within one-half hour. The data from the third orbit will be available about 3.5 hours later. The team member who is doing the analysis is required to be on duty at about 3 AM. The map will be generated and displayed on a graphics workstation at the TMCF.

The team member will visually examine the map and will select up to 6 targets for HIRIS. The HIRIS observations will be scheduled by updating the preliminary observations at least two orbits prior to the observation. If less than six targets are selected, one or more of the HIRIS observations will be cancelled.

The team member will prepare messages for the Navy as to whether and where to deploy buoys. A message for the surface ships will be prepared automatically and the team member will only be required to check this message before it is transmitted. The messages will be transmitted by telephone.

All of the data, including the MODIS real-time data, will be processed in the normal fashion. All of the standard products will be produced and available at the DADS in 96 hours. The team members will gain access to their data in the normal fashion by issuing an Archive-Data-Request.

The HIRIS data will be processed through Level-0 and sent to the team member via the DADS. The instructions to accomplish this are included in the data acquisition request and no further actions are needed to obtain the data. The data from the ship board sensors is collected and sent to the team member on floppy disks. The data from the buoys are collected and sent to the team member on magnetic tapes. One month after the experiment is over all of the data are in the hands of the team member. The data set is analyzed by several graduate students over the next four years. The team member will be responsible for ensuring that all of the results are properly documented and sent to the DADS.

3.4 SPECIFIC SCENARIO ILLUSTRATING MODIS CALIBRATIONS (USING GROUND TARGET)

The scenario presented here (Figure 11) provides a chronological summary of how calibration operations may proceed in the event that a science team member wishes to have the MODIS instrument undergo a special calibration. The scenario attempts to identify who will be involved and how they will interact. Since the scenario assumes that routine calibration planning is done in one week blocks, most of the steps in the scenario will be occurring simultaneously as each of the weekly plans progresses through the system.

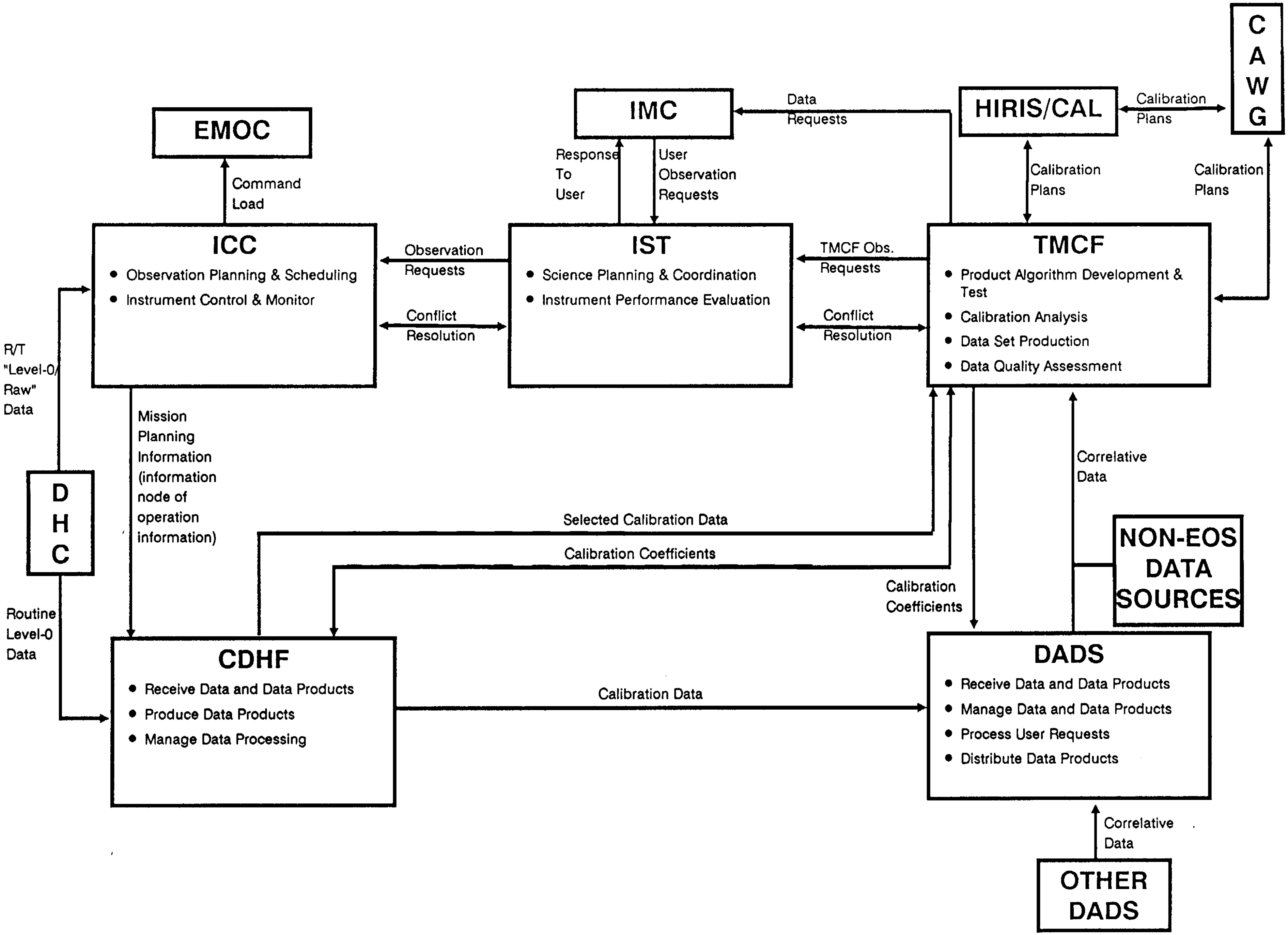


Figure 11. Calibration Scenario

In this particular scenario, we assume that a MODIS science team member wishes to test the MODIS instrument by putting the instrument in a special operations mode. Simultaneously we assume he wishes to acquire a set of calibration coefficients and other data, but is not certain exactly what procedure to follow. His point of contact for a study of this nature is the calibration scientist who leads the ICT. The ICT normally maintains and evaluates the instrument calibration. It is a resource for all issues concerning calibration.

The time T in the scenario below is the time that a calibration sequence is actually performed.

T minus 6 weeks: The science team member notifies the ICT of his concern with the MODIS calibration and requests that a particular calibration sequence be performed to test his hypothesis. The ICT concurs and adds the requested test to its next planning meeting in one week.

T minus 5 weeks: The ICT as part of its normal operating procedures consults with the HIRIS CAL and with other calibration teams of instruments on the EOS platform, informing them of the upcoming calibration plans. The science team member request has been incorporated in the MODIS calibration plan. The calibration observation plans of the two or more instruments are coordinated so that instrument comparisons are possible.

T minus 4 weeks: The ICT decides on a schedule of observations that they want for a one week period, four weeks in the future. They wish to examine intensively their Earth calibration targets as a response to the team member request. The calibration scientist, or his designate in the ICT, using an interactive menu-driven program developed jointly with the IOT, determines the times (GMT) and orbit numbers when the EOS platform will be over the selected targets within 10 degrees of vertical during the week in question. The ICT incorporates this derived information in the proposed observation plan, an example of which follows.

3.4.1 Initially Proposed Weekly Schedule

All days: Deploy solar diffuser plate on one orbit each day as satellite crosses the Earth's terminator (nearest 00 GMT).

Day 1: Normal operations. No special mode changes.

Day 2: Observe Earth targets: White Sands, Central Sahara, the Atacama desert, and Greenland during orbits n, n+1, and n+8.
MODIS-T in nadir position.
During a night orbit, sequence lamps through 3 levels.
Tag all special data sets for CDHF/TMCF.

Day 3: Observe Earth targets: South Pacific region and White Sands during orbits n+2 and n+4.
MODIS-T in nadir position.
Tag data for CDHF/TMCF.

Day 4: Night time orbit: observe dark side of Earth, perform spectral calibration, and perform electronics calibration.
Tag data for CDHF/TMCF.

Day 5: Observe targets: White Sands, the central Sahara, the Atacama desert, the South Pacific region, and a second South Pacific region.
MODIS-T in nadir position.
Tag data for CDHF/TMCF.

Day 6: Observe targets: the Arabian peninsula, Alice Springs, and the Kalahari Desert.
MODIS-T in nadir position.
Tag data for CDHF/TMCF.

Day 7: Observe targets: White Sands, the central Sahara, and the two South Pacific regions.
MODIS-T in nadir position.
Tag data for CDHF/TMCF.

3.4.2 Scheduling and Commanding

T minus 3 weeks: The science team leader received the proposed calibration plan from the ICT one week ago. He also received proposed observation plans from several other science team members. As part of the initial screening process, the plans are entered into an expert system on a computer which identifies possible conflicts in observations. The science team leader and science team members are provided with copies of the list of observation conflicts. The science team leader in consultation with the science team members reviews the conflicts. The ICT proposal to observe the Atacama desert on days 2 and 5 requires MODIS-T to be in the nadir position which conflicts with proposed ocean chlorophyll observations requiring MODIS-T to be in a tilt position. The science team leader decides ocean chlorophyll measurements have higher priority based upon IWG guidelines and eliminates the Atacama desert observations from the ICT observation plan. The conflict free plan is sent to ICC using the IST.

T minus 2 weeks: ICC tests the plan on their simulator and finds no problems. ICC in consultation with EMOC reviews the impact of the plan on the platform operations. In this case we assume a conflict is found requiring the ICT to cancel or re-schedule the night observations of the lamps scheduled on day 2. ICC notifies the science team leader who in turn notifies the ICT of the conflict. The ICT revises their plan to have the night observations on day 3 rather than day 2. The conflict resolution procedure described above is repeated with no further observation changes required in the second go-round. The HIRIS CAL and other instrument calibration teams are kept informed of all developments within MIDACS relating to the coordinated calibration plan.

T minus 1 weeks: The ICC writes the command sequences which will be executed in the following week. These command sequences will include a tag which will be appended to the header of the data requested by the ICT so that they can easily identify the data sets that they requested. An alternative scenario would require the ICT to simultaneously notify CDHF of the observations plan and require CDHF to somehow extract the requested data from the data stream.

T plus hours: The CDHF writes the extracted data to a disk at the CDHF. A mail message is sent to the ICT notifying them that new data have arrived. The ICT downloads the new data to their TMCF for more detailed analysis. A copy of a subset of the calibration data acquired as a result of the science team member's earlier request is transferred to his TMCF either electronically or by overnight mail as appropriate.

T plus 3 days: The ICT contacts the IMC and requests the HIRIS data taken in the plan be sent from their DADS to the ICT.

T plus 5 days: The ICT receives the HIRIS data.

T plus 1 week: Both the ICT and the interested science team members start using the Earth data for more detailed analysis of the MODIS instrument performance. Much of this analysis may be of the form of interactive image processing using a version of the Land Analysis System (LAS) software of Landsat or PACE (the software package used by the Canadian Centre for Remote Sensing). Typically the HIRIS spatial and spectral resolution would be degraded to match the MODIS resolution and then the differences between the two equivalent images would be studied. These analyses may confirm previously observed instrument changes have occurred, may lead to reprocessing, or the development of new calibration algorithms.

T plus several weeks: After several weeks of analysis of the satellite data sets and the corresponding ground truth data sets, the ICT decides that the calibration coefficients have changed. The science team is informed of these developments. Since the changes indicate that a reprocessing of some of the data, the consequences are discussed with the science team. If it is decided to start reprocessing, an updated table of calibration coefficients is sent to the CDHF with the times of their validity. Simultaneously, the ICT sends this information to the DADS for archiving.

3.5 SPECIFIC SCENARIO ILLUSTRATING ALGORITHM DEVELOPMENT AND IMPLEMENTATION

Algorithm development and implementation will be occurring both prior to launch and after launch. In this scenario, Figure 12, we list some of the steps that may be encountered in a typical developmental program with a typical time line.

An algorithm developer will have several points of contact within MIDACS. First will be the science team leader and other science team members. At science team meetings and through the Science Management Plan, all developers will be kept informed of what algorithms are being developed. A second point of contact is the SDST. The SDST will be polling the team members to determine if there are certain algorithms that they should develop so that several team members will not unnecessarily duplicate each others work. The SDST will examine the computer code developed by the team members and, if necessary, will modify it so as to most efficiently use the computer architecture of the CDHF. The SDST will also keep the team members informed of EosDIS programming standards and EosDIS standards for data formats. They will aid the science team members in meeting Eos goals.

T in this scenario is the algorithm implementation date at the CDHF.

T minus 3 to 5 years: The science team member receives sufficient computing resources from the MODIS Project Office so that he can start algorithm development.

T minus 2 years to T minus 2 months: A prototype algorithm is developed and debugged by a science team member. Validation studies such as those discussed in the team members proposals will be performed during this period. Each team member is assumed at this point to be responsible for acquiring the needed correlative data. Simulated MODIS datasets will also be required (and possibly provided) by the team members prior to launch. Validation study results, source and object codes, and technical reports such as user's guides will be delivered for storage in the DADS. The preliminary version of

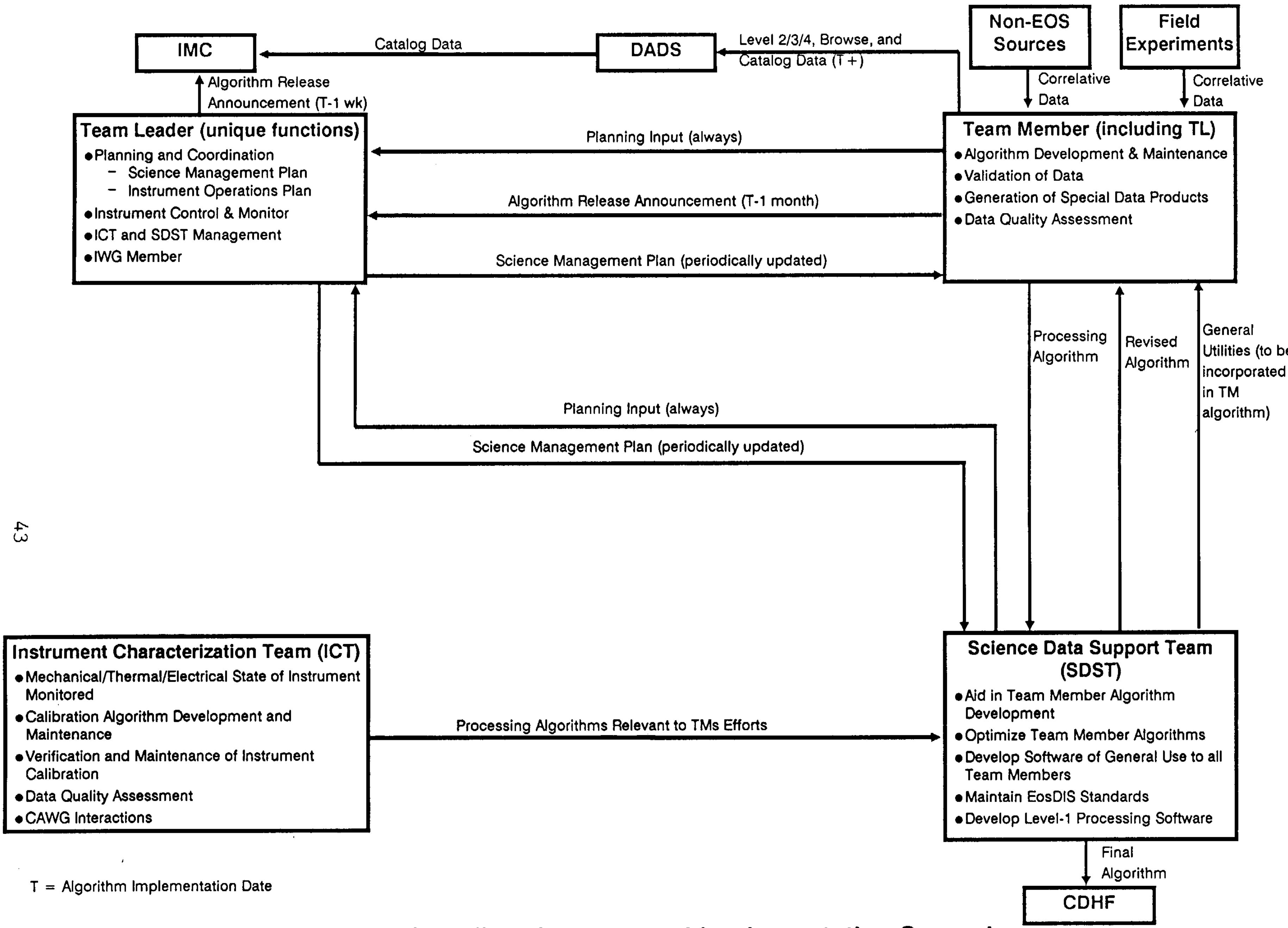


Figure 12. Algorithm Development and Implementation Scenario

the algorithm is submitted to the CDHF for timing tests. Computer scientists at the GSFC TMCF node and CDHF (the SDST) begin examination of the software code and assist the team member to look for methods to increase the efficiency, such as vectorization. The SDST also provides the science team member with some subroutines which aid in his algorithm development, such as some data input/output and plotting subroutines. The science team member continues to check the accuracy and validity of the algorithm. Each team member will not send the algorithm to the CDHF for testing. The SDST will collect and optimize the I/O.

T minus 2 months to T minus 1 month: Using lower level MODIS data generated by the CDHF and other Eos and non-Eos data which is routinely required for the processing and using the CDHF computers (simulated data prior to launch), the science team member and computer scientists have interacted to increase the code efficiency, with runs requiring about 1/3 to 1/100 the computer time that the initial code required. No loss in accuracy has occurred and the CDHF computer architecture is fully exploited. It appears that a data product with desired accuracy is being generated by the algorithm. The SDST team has also aided the team member in defining methods of acquiring other Eos data required for the algorithm to work and in acquiring non-Eos data such as ground truth data, which may be routinely incorporated into the data processing.

T minus 1 month: The algorithm is formally delivered to the CDHF by the science team member, along with all certification and DQA criteria needed for autonomous processing. Upon implementation, proposed Algorithm Release Announcement (ARA) is sent to the team leader. The ARA contains such information as a description of the algorithm, the data products it will generate along with an estimate of their accuracy, the period of time planned for coverage, the area coverage, the version number, references to user's manuals, and references to the pertinent supporting scientific literature. The object of the release announcement is to keep the team leader informed and to allow the team leader to inform IMC and the scientific community at large of MODIS activities.

T minus 1 week: The CDHF automated/expert system processing code is updated to bring the new algorithm on line. The science team leader sends an Algorithm Release Announcement to the IMC, which states the algorithm will be implemented in one week and gives information on what standard data products will be produced. All team members and the Eos Project Office among others will be kept informed this way.

T: The algorithm is applied to Level-1B data and generates a Level-2 product. Browse, metadata, and catalog data are generated. The certification criteria are tested. As explained above, T is the time that the algorithm is actually implemented and may not be the actual launch time. After MODIS is placed in orbit, it may undergo a period of testing known as the activiation period. The calibration of the instrument will be tested and all the algorithms used to generate geophysical parameters will probably be tested intensively. The activation period will last from several weeks to several months and may differ from algorithm to algorithm. Thus the time T may be several weeks to months after the launch. The earlier data and the currently incoming data will need to be simultaneously processed following the official implementation at time T.

T plus 1 day: DQA indicates a change in the algorithm is needed. For the purposes of this scenario, we assume that the initial validation tests indicate a problem exists with the algorithm and that the certification criteria are not being met. The CDHF withdraws the algorithm from routine processing. The defective data are sent to the DADS as uncertified and are only available to the science team.

T plus 2 months: The science team member has located the problem in the code and fixed it. The revised algorithm is resubmitted to the CDHF and the CDHF reinstalls it in its Level-2 processing stream.

T plus 2.2 months: Archival of the geophysical parameter starts since it is now a certified standard product. The science team leader, based upon the most recent validation studies, certifies the algorithm and issues a new Algorithm Release Announcement. Simultaneously, retroactive processing on the backlog of data, taken prior to the implementation of the algorithms, is used to derive the new standard product. The required input data is acquired from the DADS and sent directly to the CDHF for processing at twice the processing rate.

T plus : As the MODIS experiment continues, the scientific algorithm is updated and maintained as required. The maintenance of algorithms is an ongoing aspect of the experiment.

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APPENDIX A
MODERATE RESOLUTION IMAGING SPECTROMETER (MODIS) SCIENCE TEAM MEMBERS BY DISCIPLINE WITH A PRELIMINARY PARTIAL LISTING OF ASSOCIATED SPECIALIZED AND STANDARD DATA PRODUCTS

ATMOSPHERIC SCIENCES

ATMOSPHERIC AEROSOLS:

1. Yoram J. Kaufman, Science Systems & Applications, Inc., Seabrook, MD; "Global Monitoring of Aerosols Properties - Aerosol Climatology, Atmospheric Corrections, Biomass Burning, and Aerosol Effect on; Clouds and Radiation."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Aerosol climatology
   b. Atmospheric corrections
   c. Biomass burning
   d. Aerosol effect on clouds and radiation.

2. Michael D. King, GSFC, Greenbelt, MD; "Determination of Cloud and Aerosol Radiative and Microphysical Properties from MODIS-N."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Aerosol optical thickness
   b. Aerosol size distribution
   c. Aerosol index of refraction
   d. Aerosol single scattering albedo

3. Didier Tanre, Univ. des Sciences et Techniques de Lill, Villeneuve d'Ascq, FRANCE; "Global Aerosols Monitoring Experiment from Space G.A.M.E.S. (Transport and Radiative Properties)."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Aerosol radiative properties
   b. Aerosol transport processes

CLOUDS:

1. W. Paul Menzel, NOAA/NESDIS, Madison, WI; "The Investigation of Cloud Properties with MODIS-N."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Cloud properties with MODIS-N

2. Joel Susskind, GSFC, Greenbelt, MD; "Determination of High Resolution Atmospheric and Surface Parameters from MODIS-N."

Proposed Research Studies and Examples of Candidate Data Products:

a. Effective cloud fraction
b. Cloud top pressure
c. Outgoing longwave radiation
d. Longwave cloud radiative forcing

RADIATIVE TRANSFER MODELS:

1. Alan H. Strahler, Boston University, Boston, MA; "Mapping Spectral Directional Radiance, Spectral Directional Surface Radiance, and Spectral Bidirectional Reflectance; Distribution Functions for Land Surface Covers using MODIS-T."

Proposed Research Studies and Examples of Candidate Data Products:

a. Spectral directional radiance
b. Spectral directional surface radiance
c. Spectral bidirectional reflectance
d. Distribution functions for land surface covers using MODIS-T

LAND SCIENCES

VEGETATIVE PROPERTIES:

1. Christopher O. Justice, UMd, College Park, MD; "Monitoring Global Vegetation Dynamics using MODIS-N."

Proposed Research Studies and Examples of Candidate Data Products:

a. Vegetation index
b. Vegetation dynamics
c. Atmospheric corrections

2. Vern Vanderbilt, ARC, Moffett Field, CA; "Estimation of Photosynthetic Capacity using MODIS Polarization."

Proposed Research Studies and Examples of Candidate Data Products:

a. Photosynthetic capacity using MODIS polarization.
b. Polarized leaf reflectance

CARBON AND OTHER BIOLOGICAL CYCLES:

1. Frank E. Hoge, Wallops Flight Center, Wallops Island, VA; "Species Variability and Improved Carbon and Nitrogen Cycling Determinations."

Proposed Research Studies and Examples of Candidate Data Products:

a. Species variability
b. Improved carbon and nitrogen cycling determinations

2. Alfredo R. Huete, UAz, Tucson, AZ; "Determination of Dynamic Vegetation - Soil - Organic Carbon Interactions with MODIS Instrument Observations."

Proposed Research Studies and Examples of Candidate Data Products:

a. Determination of dynamic vegetation - soil - organic carbon interactions

3. Steven W. Running, University of Montana, Missoula, MT; "Canopy Carbon and Water Fluxes from Terrestrial Vegetation: Development of EOS/MODIS."

Proposed Research Studies and Examples of Candidate Data Products:

a. Canopy carbon fluxes
b. Canopy water fluxes
c. Normalized difference vegetation index

PHYSICAL PROPERTIES:

1. Jan-Peter Muller, University College London, London, England, UK; "Mapping the Composition and 3D Structure of Terrestrial Surfaces from a Synergistic use of EOS Instruments and Numerical; Simulation Models."

Proposed Research Studies and Examples of Candidate Data Products:

a. Composition of terrestrial surfaces
b. 3D structure of terrestrial surfaces
c. Simulation modelling

2. MODIS Team Leader - Vincent V. Salomonson, GSFC, Greenbelt, MD; "The Dynamics of Snow and Ice Cover Over Large Areas and Relationships to Surface Radiation Balance Components as Observed; by MODIS N and T."

Proposed Research Studies and Examples of Candidate Data Products:

a. Snow and ice cover
b. Surface radiation budget components
c. Dynamics of snow cover

3. Zhengming Wan, Institute of Remote Sensing Application, Beijing, CHINA; "Land Surface Temperature Measurements from EOS/MODIS Data."

Proposed Research Studies and Examples of Candidate Data Products:

a. Land surface temperature measurements

<u>OCEAN SCIENCES</u>

GLOBAL BIOLOGICAL PROPERTIES:

1. Mark R. Abbott, OSU, Corvallis, OR; "Studies of Primary Production in the World Ocean Using Data from the Moderate Resolution Imaging Spectrometer (MODIS)."

Proposed Research Studies and Examples of Candidate Data Products:

a. Primary production in the world ocean

2. Wayne Esaias, GSFC, Greenbelt, MD; "Oceanic Productivity and Photosynthetic Efficiency."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Ocean chlorophyll
   b. Diffuse attenuation coefficient
   c. Oceanic productivity
   d. Photosynthetic efficiency

3. Otis B. Brown, UMiami, Miami, FL; "Infrared Algorithm Development for Ocean Observations with EOS/MODIS."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Infrared algorithm development for ocean observations
   b. Multiple orbit averages with reduced spatial resolution
   c. Mesoscale oceanic phenomena

4. Howard R. Gordon, UMiami, Coral Gables, FL; "Algorithm Development for Ocean Observations with EOS/MODIS."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Algorithm development for ocean observations
   b. Raleigh scattering calculations

5. Robert H. Evans, UMiami, Miami, FL; "Processing and Calibration for Visible Ocean Observations with EOS/MODIS."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Processing algorithms for visible ocean observations
   b. Multiple orbit averages with reduced spatial resolution
   c. Mesoscale oceanic phenomena

REGIONAL BIOLOGICAL PROPERTIES:

1. Kendall L. Carder, University of South Florida, St. Petersburg, FL; "High Spectral Resolution MODIS-T Algorithms for Ocean Chlorophyll in Case II Waters."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Ocean chlorophyll in case II waters

2. John Parslow, CSIRO, Hobart, Tasmania, AUSTRALIA; "Ocean Color Algorithm Development and Processing of MODIS-T Data for Australian Waters."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Ocean color for Australian waters

PHYSICAL PROPERTIES:

1. Ian Barton, CSIRO, AUSTRALIA; "The use of MODIS-N Data in the Derivation of Accurate Global Sea Surface Temperature Data Sets."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Global sea surface temperature

2. Dennis K. Clark, NOAA/NESDIS, Washington, DC; "Marine Optical Characterizations."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Marine optical characteristics

CALIBRATION STUDIES

1. MODIS Team Leader - Vincent V. Salomonson, GSFC, Greenbelt, MD; "The Dynamics of Snow and Ice Cover Over Large Areas and Relationships to Surface Radiation Balance Components as Observed; by MODIS N and T."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. MODIS-N calibration
   b. MODIS-T calibration

2. Robert H. Evans, UMiami, Miami, FL; "Processing and Calibration for Visible Ocean Observations with EOS/MODIS."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Calibration for visible ocean observations

3. Philip N. Slater, UAz, Tucson, AZ; "Absolute Radiometric Calibration of MODIS-N and other EOS Imaging Sensors."

   Proposed Research Studies and Examples of Candidate Data Products:

   a. Absolute radiometric calibration of MODIS-N

APPENDIX B
ISSUES RELATED TO REQUIREMENTS ON DATA

To ensure that the science team members' requirements relating to the MODIS data are properly addressed, certain fundamental issues must be considered, some of which may directly impact the design of the MODIS instrument and the polar platform itself.

1. One of the data requirements is the location of a pixel with an error of less than 10% of the largest pixel size (which is about 1000 m) at nadir. This requirement can be met only through the accurate determination of the sub-satellite position and accurate attitude information. The current platform design will result in more than a 100 arc second uncertainty in attitude and 50 m of uncertainty in sub-satellite position determination, which will not meet the requirement. So, MODIS must have its own star tracker which can determine the attitude within 4 arc seconds, and will require the platform to determine the sub-satellite position uncertainty to less than 10 m.

2. Another requirement on the data is that, after corrections are made, the bit error rate (BER) should be less than 10^{-8}. At a BER of 10^{-12}, on average only one bad MODIS bit will be encountered every day. However, at a BER of 10^{-8}, 10^4 bad bits will be encountered daily. The packets with uncorrectable errors will be flagged as such by the DHC. Each packet will consist of up to 10^4 bits. In general, it will not be possible to identify the bad bit in a flagged packet. As a result, it may be necessary to reject up to 10^8 bits of MODIS data per day; this is the equivalent of ten seconds of data out of 86,400. The current Grade II service of the TDRSS will meet this BER requirement.

3. A third requirement describes the completeness of MODIS data coverage. The MODIS instrument is capable of operating simultaneously in two modes. These have been termed the "survey instrument" mode and the "observatory instrument" mode. The survey instrument takes continuous observations and regularly observes the entire Earth. The observatory instrument acquires data only in response to a user's data acquisition request (DAR). Each of these modes will have a different level of allowable data loss.

   When data collection is dictated by a response to a DAR, there is a specific requirement for the data. The need for the data may be critical (e.g., supporting and directing aircraft flights), or alternate data may be acceptable (e.g., from two days later). It must be assumed that a 100% coverage requirement applies to the DAR, and that none of the requested MODIS data may be lost. Should a conflict arise that will result in the loss of the data covered by the DAR, then the MODIS science team leader must be involved in the resolution of the conflict.

   When data collection is not dictated by a response to a DAR, the extent of lost MODIS data will be driven by the science requirements on the accuracy of the geophysical parameters (including the radiances). These requirements have not yet been formally stated, and will no doubt vary from parameter to parameter. It may be necessary to conduct system simulation studies to assess the impact of data gaps on the product accuracies. However, it is clear that no spatially systematic gaps in data coverage will be tolerable. Only non-systematic (random) data losses will be allowable.

   At present, the requirement on the data coverage is not specified. To help to understand this requirement, consider the following computation: completeness to only the 99% level would result in a loss of 15 minutes of coverage per day. At the 6.5 km per second velocity of the satellite, this is about 51° in latitude, or about a 5600 km along the orbit with the full swath. Because MODIS data will be used to produce products with global coverage, missing data will degrade the quality of the final product. The Science Team may require that no systematic MODIS data losses occur.

4. The proposed data blocking categories are discussed in Appendix D. Here, we consider the granularity of the MODIS data. We define a MODIS data granule as the smallest block of MODIS data that may be easily accessed from the archived data products. The definition of the MODIS data granules, as opposed to the time/space domain of a MODIS data product, is of fundamental interest to a MODIS team member because it determines the time/space resolution to which a MODIS data product will be segmented, addressed, and ordered. The MODIS science team may wish to recommend different granule definitions for the Level-2 and Level-3 data products (e.g., swath or swath cube/non-rectified image or image cube versus a rectified image).

APPENDIX C

LIST OF ACRONYMS

AIRS	Atmospheric Infrared Sounder
AMRIR	Advanced Medium-Resolution Imaging Radiometer
AMSU	Advanced Microwave Sounding Unit
ARA	Algorithm Release Announcement
CAWG	Calibration Advisory Working Group
CDHF	Central Data Handling Facility
CDPP	Calibration Data Products Plan
CIMP	Calibration Implementation and Management Plan
CZCS	Coastal Zone Color Scanner
DADS	Data Archive and Distribution System
DAR	Data Acquisition Request
DBMS	Data Base Management System
DHC	Data Handling Center
DIF	Data Interface Facility
DQA	Data Quality Assessment
EMOC	EOS Mission Operations Center
EOS	Earth Observing System
EosDIS	EOS Data and Information System
EOSP	Earth Observing Scanning Polarimeter
EPOP	European Polar Orbiting Platform
ERBI	Earth Radiation Budget Instrument
EVE	Explosive Volcanic Eruptions
GGI	GPS Geoscience Instrument
GLRS	Geoscience Laser Ranging System
GMT	Greenwich Mean Time
GOES	Geostationary Orbiting Environmental Satellite
GOMR	Global Ozone Monitoring Radiometer
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HIRIS	High Resolution Imaging Spectrometer
HIRRLS	High Resolution Research Limb Sounder
ICC	Instrument Control Center
ICT	Instrument Characterization Team

IMC	Information Management Center
IOP	Instrument Operations Plan
IOT	Instrument Operations Team
IPEI	Ionospheric Plasma and Electrodynamics Instrument
IST	Instrument Support Terminal
IIWG	Interdisciplinary Investigator Working Group
IWG	Investigator Working Group
JPOP	Japanese Polar Orbiting Platform
LAS	Land Analysis System
LAWS	Laser Atmospheric Wind Sounder
LIS	Lightning Imaging Sensor
LTPSP	Long-Term Platform Science Plan
Mbps	million bits per second
MIDACS	MODIS Information Data and Control System
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectrometer
MODIS-N	MODIS Nadir-viewing scanner
MODIS-T	MODIS Titlable scanner
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPOP	NASA Polar Orbiting Platform
OLR	Outgoing Longwave Radiation
PI	Principle Investigator
PSC	Platform Support Center
SAFIRE	Spectroscopy of the Atmosphere Using Far-IR Emission
SAR	Synthetic Aperture Radar
SDST	Science Data Support Team
SMP	Science Management Plan
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPOT	Systeme Probatoire d'Observation de la Terre
SWIRLS	Stratospheric Wind Infrared Limb Sounder
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
TES	Tropospheric Emission Spectrometer
TLCF	Team Leader Computing Facility
TMCF	Team Member Computing Facility

TRMM	Tropical Rainfall Monitoring Mission
WIOP	Weekly Instrument Operations Plan

TRMM	Tropical Rainfall Monitoring Mission
WIOP	Weekly Instrument Operations Plan